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I presume you know I’m Cyril Hilsum. That’s how we start. And I was born some eighty-six and bit years ago in the East End of London. I was born in a road called Diggon Street and I was a bit upset going back there a few years ago and discovered that not only doesn’t the house still exist, but the street itself has been expunged. So I think they were trying hard to ensure there was nowhere where they could put a blue plaque if ever they wanted one. But I pointed out they could always put one in the middle of the road. There is a road still running through there. My family was very poor. There were three boys in the family, obviously a father and mother, and my dad was a street trader and my mother helped him, so my elder brother, Charlie, generally was looking after us at weekends. I went to an elementary school very early, when I was about three, and that was quite possible then, I think it would be more difficult now. I went because I was being a nuisance at home mostly and I could read by then, having learnt to some extent through my brother I suppose, who’s two and a half years older than me. And my younger brother is one and a half years younger. And mostly I remember from elementary school is sleeping in the afternoon where there seemed to be brown curtains and we were put on camp beds, I suppose. So I think it was effectively a nursery school. But we did learn some lessons and then progress to, through infant school to elementary school and I did fairly well at elementary school and was put in the top class quite early for my age, I think I was in the top class for several years and got to know the master because then you had more or less one master for the class and we kept in contact. And he was a great influence on me and helped me a lot. I don’t know if there’s anything more you want to know. My recollections are of a lot of activity, particularly round about 1936 when we had the Black Shirts coming, my – I should say my parents were Jewish, I was brought up until I was thirteen as a Jew when I gave it up and have never looked back, because I didn’t, found I didn’t believe in religion. I wouldn’t say I’m an atheist but I’m certainly an agnostic and I have had no connection with the religion since then. I don’t know whether there’s much else I can say.

Well, I’ve got a load of questions based on what you’ve just told me, so it’s... [laughs]  

Go ahead then.
Could we perhaps start with your parents actually? Could you describe what your father was like to me? What was his name?

My father was Ben, his name was Benjamin, Ben. He was very intelligent and I always thought he was frustrated because he’d had to leave school when he was thirteen or fourteen to earn money and he was very interested in learning and later on he was able to do some things like that and he ran further education lessons, particularly in first aid and home nursing, because when I say he was frustrated I think he always wanted to be a doctor. In fact that is relevant because I’m pretty certain he wanted me to be a doctor and I did not want to be a doctor, I wanted to be an engineer or a scientist. I didn’t put it in those words but I knew I liked putting toys and things together and taking them apart again, quite often they didn’t work and I could work out why they didn’t work. But I responded to this by essentially ensuring I fainted whenever there was any medical question coming up and so it became obvious that I was not going to be a doctor. But I did help in the first aid and home nursing lessons, which really is a criticism, and it was one I could take at the time, because what was wanted was models. When the people did exams, and these exams were quite important because they qualified the people to be the first aid representative in a company, in a factory, and they were given a certificate that they had passed the examination, which meant of course there had to be an examination. And the examination would be to check that they knew the contents of the book on first aid – home nursing came later – and that would involve that if there were pressure points that needed for if there was an accident, and in particular if a limb was broken, they would have to know what slings to put on and things like that. And there was a practical side to this as well as a written examination and they had to have models and dad would bring me in as the model, and being quite alert and knowing that his reputation depended on people getting through the examination, and of course he didn’t do the examination, he would ensure that I was the model for the borderline candidates. So the candidate would start doing something like putting a sling on and I would say, ‘That’s not where it goes’. And they’d say, ‘Oh, where does it go?’ I’d say, ‘Put it higher up’. ‘Oh, thank you.’ And then they would do something else and I’d say, ‘That’s not the right pressure point’, you know when he comes along you’re pressing on the wrong place. ‘Oh, where do I press?’ ‘Press a bit higher.’ Well, as a result of course, it was normal for them to actually reward the model with a few pence or so. My rewards were generally greater than a few pence, so I can remember this quite clearly that the examination was a time we looked forward to, and of course as a result I did learn quite a lot of first aid and home nursing. Dad did this for a number of years in the evenings. I don’t think he ever fully recovered from not being able to practise at a
reasonable intellectual level. He did become quite a good politician, a local politician, and he could speak very well and I think I probably owe quite a bit of my powers of communication to him and of course that has come through to my daughter who makes a living through communication. She is the International Editor for Channel 4 News and can be seen on television and she doesn’t remember her grandfather much, but it is quite possible that she has inherited some of those traits, as I have done. [08:05] My mother was a very simple woman whose education had been limited and she just was a mother and a housewife, though she helped in the markets when my father had to go out and try and earn some money.

What was your mother’s name?

Ada.

What was… can you describe what her personality was like to me?

She was warm, quite large. My dad was slim, neither of them was very tall. My mother had looked after my grandfather. I know she had worked in the house and looked after my grandfather and still told the story of when she came home and found him dead, it affected her. She was then feeding me and said that she lost her breast milk as a result, which may account for the fact that my teeth were very bad. So people said, I don’t know whether this is true, but that was one of the family stories that Cyril’s teeth are bad because his grandfather died. Who knows?

Do you know how your parents actually met?

As I said, she worked for the family. She came from Bristol and I think at that time even in poor households they often had some young person helping with the housework. I remember we, for example, had a very young Irish girl working in the house, though we didn’t have two pennies to bless ourselves with, presumably we could provide some food and it was necessary to have somebody before Charlie became old enough to look after us. But I suspect that this was a young girl, probably sixteen or seventeen who’d come over from Ireland and looked after us and was really one of the household. And I imagine that it was similar that my mother was working as a [telephone ringing] a helper.
Sorry about that. Yes, as I was saying, mum worked for the family. My dad went off, he was called up – now we’re talking about the First World War before I was born, obviously – he went and he was, I know that he was injured, he wasn’t wounded, he was injured. I think a tank went over his foot or something like that, he may have been quite careless. But he came back and was… and my mother looked after him. And they must have got married around, probably about 1920, something like that. But I’m pretty certain that they knew each other before that because she was in the household.

*Did your dad ever talk about the war?*

Not to me, no. He talked more about the second war, when we get to that, because he was involved in that. But I don’t remember him saying anything about the first war, I think I discovered it mostly by reading things and reading the history. [11:40] The history of the family is slightly complicated because – let me get this straight – my great-grandfather was Dutch, Hilsum is a Dutch name and has various different spellings and things, my great-grandfather, yes, my great-grandfather was Dutch and came to England, married an English girl and got her to take Dutch nationality and then his son, my grandfather, also came to England and married an English girl and got her to take Dutch nationality. As a result of that they produced my father. My mother was born in Bristol but her parents were Polish. So my background is Dutch-Polish in that sense, though I have no links with either country, though I can occasionally trace things back. And my daughter got interested in genealogy and did trace the family back and my nephew has also followed that up with finding an American branch of the family. And we did find a book that was written by a Polish lady, which explained one thing that we had often puzzled on. Because Hilsum is an unusual name, which is quite useful because you can trace things back, and we knew that if you put in ‘Hilsum’ into different countries’ phone books and things, you get people who may or may not be related, they probably are related, and there’s a Paris branch of the family and we knew there was a Michel Hilsum, was quite a well-known mathematician, but there were some others too and we couldn’t trace those. But anyway, this Polish book – translated into English obviously – spoke about the unfortunate connection with the Hilsum family, which naturally we traced through to find out what she was talking about and it appeared that the author’s niece had been in Amsterdam and had met a Louis Hilsum, I think, and he had proved to be a rogue. He blotted the copybook by going bankrupt or something and in the end he was
drummed out of Amsterdam and moved to Paris where the book goes on to say, he went out to buy cigarettes and did not come back, though he was seen at Gare du Nord talking to a lady of easy virtue. Now the interesting part is not that, though that’s of interest on its own, but in fact they had moved to Paris and the book named the children and we could see that Michel had become a mathematician. Two of the others had an interesting career. One of them ran the Narodny Bank in Paris. Now Narodny of course was the Russian bank in Paris, which became the communist Russian bank in Paris. The other one ran the communist party press in Paris. So I must say I was rather relieved that we didn’t find this out until I had left the Ministry of Defence. I don’t know that the people who checked my security would have been thrilled at finding that there was a branch of the family that had this mysterious past, though in fact obviously I had no contact with them at any time. But that was, the interesting part is the Dutch side that they came over and settled in England and they actually had reasonable careers. [16:30] I can’t say that my father had a reasonable career. He was a street trader, he had a stall in Shepherd’s Bush market and another stall in Petticoat Lane and later on he did get some jobs, in the sense jobs that had a salary. He worked selling ice-cream in cinemas and then he worked for the Royal Mint for a time, and then he worked at Ceylon House as a porter. But as you can see, it was clear right from the beginning that if I was going to get on reasonably it was entirely up to me.

What did your father actually trade in?

Anything that he thought could make money, but chocolates quite a lot. He would buy chocolate and then he would paint, at those times – not now – the price was on chocolate bars in a little gold circle, it would say 2d or something, and these were old ds of course, not the modern ps, so they were half what they are now. And he would, with gold paint, paint over the price so it wasn’t obvious what the price was and then he could charge more. He also – that’s mostly what he sold when he went to race courses and places like that – with the stalls, the Petticoat Lane stall was mostly caps, flat caps, and the Shepherd’s Bush stall was chamois leather that he used to prepare. And in those days people bought chamois leathers for polishing. So we scraped by, I would say, there was never money to spare; we didn’t have holidays or things like that. Though in fact they somehow always bought us presents. I remember when I got my eleven-plus scholarship – and we’ll come to that I’m sure – that when I came home at lunchtime, because we came home at lunchtime for lunch, sandwiches and things, sometimes proper lunch, there was a pinboard there with – battery driven obviously – and you could bagatelle balls around and lights would go and things, and I went back to school really thrilled that I had this waiting for me when I came back.
But when I came back it had gone. It wasn’t there. I said, ‘What’s happened to my pinboard?’ My mum said, ‘Your dad couldn’t get good scores on it so he’s taken it back’. So he took it back and came back with one which I must admit was probably more expensive, I’m not even sure I haven’t still got it. Because this had a glass top and green sides, leatherette, really quite posh and must have been more expensive unless he did some kind of deal. But I was amused later on to think that he changed it because he couldn’t get high scores. It was my present after all. I didn’t get a chance to know whether I could get high scores or not.

What sort of chap was he, your father?

He was very intense. Always spoke quite quickly and had strong views. We didn’t often go out. He had a big family. They both had big families, this is one of the points. My mother had had something like twelve or thirteen brothers and sisters, though some of them had died young. I remember one certainly, Mark died after I knew him. Dad’s family were smaller but still had about six. There were two, there were two sisters he had and I think three or four brothers. So there were a fair number, but we rarely went out to see them and I couldn’t understand this, why, and he argued that they didn’t come and see him either. And I said, ‘Well, so what?’ He said, ‘Well it’s easier for them to come out to where we live than for us to go to where they are’, and I could never quite work out the symmetry of that. He had the view that it was easier. We were, we lived in, with the war which we haven’t got to, our house was bombed and we had to move, so we actually moved to Streatham which became the family home for a number of years. We probably moved there in about 1942 and it was there that he claimed that his brothers couldn’t see him even though it was easier for them to get out to Streatham than it was for us to go from Streatham to wherever they lived. But he had strong views, he disliked Herbert Morrison intensely and I could never quite work out why he disliked Herbert Morrison so intensely. He had such strong views that at one stage he was a communist, he definitely was a communist, he believed in this. But then he got upset, I think over Herbert Morrison, and then he became a Conservative. So although you might have thought that we were a straightforward Labour Party family, at the election in 1945 we had the distinction, by then Charlie was old enough to vote, and we actually had in the window, our window, posters for all three parties. My dad had the Conservative Party poster, my mum had the Labour Party poster and Charlie had the Liberal Party poster. I pointed out to them that there was no point in them all going along to vote since there were only three candidates, but no, they all insisted, they went out together and all voted, all neutralising their vote. Still, they said it was their democratic right and that’s what they were
going to do. So that was dad. He was always very proud of what we did. He effectively had his ambitions through his children and fortunately we all did quite well. [23:55] My brother worked for the – the older brother – worked for the LCC. He’s still alive, he’s ninety this year. He did work with Ken Livingstone for a time. Never commented on it. He worked his way up and became reasonably senior in the LCC, as it was then. Lives in Balham. My younger brother… my elder brother, they both were called up. We’ll get to my own military career later on. But Charlie was called up quite normally, he served in North Africa I seem to remember a time, there are photographs of him, he came back and married Trudy and has two children, lives in Balham. Sid, younger of course, was called up I think after the war it must have been. Let me think, he probably wasn’t… he’s a year and a half younger than me so yes, I was, in ’45 I was twenty so he would only have been eighteen and a half and originally he was going to go to UCL as I did and I think he was going to do geology, but I think later on after he’d done his military service he changed, he could have done philosophy or something like that. But he took up teaching and taught in elementary schools actually for a number of years before he went into educational research and worked for an educational research organisation. He got a PhD on a study he did called The Teacher’s Day, which was an analysis of what teachers actually did. And he of course is retired now. He lives in Lewes. He also has two children; a daughter and a son.

[26:25]

What was it like actually growing up with them? What was family life like, perhaps would be a way into this.

Well, as with most families I suppose the father wasn’t present that much. Ours was a bit unusual in that dad would also be working in the evening, often preparing the chamois leathers and sometimes doing the painting of the gold paint on the price of the chocolate bars. We were pretty happy really. Occasionally it was irritating when we knew that we were much less well-off than other members of the family. Some of our uncles had shops and things and were reasonably well-off and it was a bit irritating to have hands down clothes and things like that, which I don’t know if it happens today, but I can still remember getting a suit with Meakers on it, which is a company that’s gone out of business many years ago, that came from a well-off sister and brother-in-law of my mother’s who had a shop in Shaftesbury Avenue, very promising shop. And in fact probably one of the sons, who I knew, he’s become the richest member of the family, he’s certainly a millionaire, which is not something that we have shared. But I suppose if you actually worked out exactly what this house is worth and what I’ve got, then probably sort of on the millionaire
side, but it never seems like that. But anyway, I can remember this brown tweed suit, which I didn’t think fitted me, but my mother assured me it fitted like a glove. Had been handed down and I was never very happy with things like that. But that just increased our determination that we knew we had to manage for ourselves, there wasn’t any money available, so we had to do things. We played in the street, we had fights. In general I suppose it was like most families.

[29:08]

*What was your home actually like? Before the bombing.*

There was an outside loo, I can remember that. There was one bathroom, at least I think it was a bathroom. No, it can’t have been a bathroom. There was one room where there was a washbasin upstairs, there were… it was a terraced house with a yard and curiously enough we had a lodger. I can remember his name was Charlie Cain, a small man, I remember him. He was bald with a moustache, quite small, Charlie Cain. And he had one bedroom. We all slept, the three boys, in what seemed an enormous bed in another bedroom which was gas-lit. I can remember it had a gas mantle and I always wondered about gas mantles. There was gas upstairs, there was electricity downstairs and I know there wasn’t a bathroom because we either had, when we were young, we had an iron or metal bath that was put on the settee where we had our baths. Later on we used the public baths which we’d go to once a week. There was a kitchen outside which didn’t have a proper roof, it had a plastic, I suppose it was a plastic roof, or it may have been… it certainly had curves in it so it could have been corrugated iron. But that was, the kitchen was outside there and there was a, there was a dining room which was… there was a dining room and a parlour downstairs which were very rarely used except for visitors. So upstairs there must have been at least three bedrooms. As I say, there was one for the kids, one for dad and mum and one for Charlie Cain. Maybe the Irish girl was there before Charlie Cain came. I think that must have been because she certainly would have had her own bedroom.

*What was it like visiting a public baths?*

A queue. You went along with your towel – no, I think you were given a towel. You had a flannel and your own soap, you had to take your own soap, I remember that. I don’t know whether we took our own towel or not. I can remember a bundle, but I’m not sure what was in the bundle. And you queued up and it was in Mile End Road we went, and all three of us would go together, obviously. We, dad was very keen on cleanliness because mostly of his first aid and
also wanting to be a doctor, and he insisted that we washed pretty thoroughly each day. We
couldn’t bath but we washed pretty thoroughly and he made sure that we were clean.

[32:40]
*What was the area that you grew up in like?*

Pretty much the same as our house. I mean some of the people were clearly a bit better off than
we were. Next door there was a very nice young lady who taught the piano. Odd that in spite of
all the poverty there were people who wanted to learn the piano. We actually had a piano. Not
that any of us could play, but we had a piano. I did have some piano lessons but after three the
piano teacher said it was impossible to teach me. That was never clarified. I suspect that I wasn’t
listening to what she was saying. I was more interested in playing around.

*What do you think you were actually like as a child? Can you describe yourself?*

I never took to discipline. I would always want to know why people wanted things done, for
example. I know I queried, I said this about being clean and it was a family thing that I
complained bitterly once… I complained to people generally around that every day my mum
wants to wash me and this seemed to me to be a liberty and I didn’t get very dirty so it was not
necessary to wash me every day, but every day. And I would query things. I would query things
at school and at home as to why certain things were necessary, why were we doing these things,
which didn’t go down terribly well because often people couldn’t answer and they didn’t like to.
It would be obvious they didn’t know the answer, it was something, we’ve always done it that
way.

*Why do you think that you needed to know those things?*

I suppose it comes from having… well it may be that there was some question of why we were
worse off than other people, how, why were we in this position and other people weren’t, and
wanting to understand the reasons for it. But there was always a bit of being an outsider. It also
was, I suppose fairly obvious early on that I thought in a slightly different way from the people
around me. My mind was always quite quick and I wasn’t slow in saying what I thought. I was
never terribly worried about what people thought, which wasn’t necessarily true of everyone
around at the time. So I would say things and I certainly would always be taking things to pieces
when I could get hold of them, which wasn’t always popular because I couldn’t always put them back again.

What sort of things did you take to pieces?

Oh, toys and things mostly, if there was anything around. I wouldn’t interfere with electricity or anything like that, but I would take toys to pieces whether they were mine or other people’s.

Could you think of an example of you being quick-minded and quickly coming out with an example of something as a child?

I can’t think of any particular examples. I did act on impulse quite often. I can remember once we were fighting, our street was fighting with the neighbouring street, Copley Street, which was not unusual for us to fight, and I think we used to lose until it occurred to me that there were some iron bars in the house that my father used to erect the stall, so I went and collected these and issued them to our gang as it was, must have been all of eight or nine years old. And we started thrashing these with the iron bars until suddenly a bigger boy came along and he bashed us and stole the iron bars and I realised that I was in deep trouble now. So I had to rush there and I was very violent with my iron bar, I’m told, until they all ran away and left our iron bars so I could collect them and take them back indoors before dad discovered what had happened to them. And I did have, oh yes I did have quite a temper. In fact, they said I had convulsions when I was a baby, which I was never able to explain as a sort of medical term. There is a thing, convulsions in children, which I think now they would say was a temper tantrum, but it is said that in one of these my father took me and just took me to the doctor’s and presented me to the doctor as I was having a temper tantrum or convulsions or something. Again, I’ve got no recollection of it. I think I did have quite a temper and would lash out at people if they upset me. Not something that happens now.

Did you have any hobbies when you were growing up?

I played chess quite a lot and played table tennis quite a lot. Chess stayed with me, the table tennis to some extent stopped. It depends what you mean, growing up.

Well, let’s take the younger part of your childhood perhaps.
That’s… I was playing table tennis. I belonged to the boys’ club and would play table tennis and belonged to the chess club at school. By the time I was eleven I was at grammar school and we played chess there. But I would also play other games, I mean I played cricket, tried to play football but I was never terribly good at it, though in fact because I was small I was able to play in the teams for the children younger than me, so I was actually at school captain of the under fourteen class when I was sixteen. Nobody seemed to be worried about that, though mind you we didn’t broadcast it to the opposition, but I could keep the fourteen year olds in order, I doubt if I could keep the sixteen year olds in order. But I was quite interested in activities, I did running and things and I wasn’t what they might call a swot.

[41:26]

I was wondering as well, you mentioned that you were brought up Jewish until thirteen, how much did religion actually feature in your upbringing?

Not at all really. I mean the family worked on Saturday. I went to Hebrew classes because you were supposed to go to Hebrew classes. I never mastered Hebrew, although nobody knew it because basically as far as I was concerned the Hebrew class mostly was concerned with translating from a chapter of the Bible into English from Hebrew and I found it was easier for me to learn the English off by heart and then check with the person sitting next to me as to what the first sentence was, and then I could write out the rest from memory, which was good and they thought I was very good at Hebrew, but I never understood the language. I never had any sympathy with the logic of it, I couldn’t understand it. I suppose I could never work out why we were poorly off and others weren’t, why should that be and things, but I agreed with my parents that I would actually be bar mitzvahed when I was thirteen and that was the end of it. I wasn’t terribly popular at school, the school was an East End school which meant it was mixed. It had a mixture of Jewish kids and Christian kids. There weren’t any from other religions and that meant that the school allowed the Jewish children to take Jewish holidays and I refused to take them. I said I’m not Jewish. They said you are, I said I’m not, so I can’t take the holidays, it wouldn’t be right to take the holidays because I’m not actually sort of worshipping. The school accepted this, the other boys were furious. It was a bit like a union and I was letting down the union and of course there would have been a risk that if lots did it that the privilege would be taken away from them. So I was keener on school. I liked school and I saw no reason why I should be away from
it because of something I didn’t believe in. It wasn’t based on any great logic or philosophy, it was more a convenience thing. I saw no reason why I shouldn’t go to school.

*Why did you not believe in it?*

Because there’s no logic in it. You see, if you follow the logic of religion through, you normally come to the point where someone says well, how did the world ever exist if there isn’t a God. And you say well, how did God ever exist. Say at least you can explain there is a world and you don’t have to put conditions on it, but you’re inventing a God that is much more difficult to understand because of all of the conditions you’re putting on, like he has an interest in people that he thinks he’s created and he created the world so it’s one extra step in the logic. So you have to say, I don’t know how the world exists but I’m pretty certain that it doesn’t exist because there’s a God to create it. And that was the logic, basically, you couldn’t see any reason, it was just going too far into uncertainty. But I accept the logic that says that you can’t quite apply logic to this, so I would say I’m not an atheist, I’m not going to take the view and say there is not a God, I’m saying you just don’t know and you never will know.

*What did your parents think about your viewpoint?*

Oh, they were never terribly – I don’t think either of them were what you might call a worshipper. I mean they’d been brought up that way and they didn’t think about it, so that was what they were. I mean they would take the holidays, they would fast at Yom Kippur and would generally say they were Jewish. And my elder brother certainly really does practise. I don’t know when he started again but he certainly married quite an orthodox lady and they definitely have a Jewish household and as far as I know their children probably are the same, well I’m pretty certain the elder child is. I don’t know about the younger one, he probably is. I suspect that my younger brother also has no particular interest in religion but I haven’t talked to him about it. But essentially you can see that afterwards I, I’m just trying to think now… I married a gentile who had been religious but had almost stopped when I met her and completely stopped. We will get round to Betty. And her whole family was vaguely Christian, I don’t think they were aggressively Christian, but they would have said they were Christian if you’re talking about the census form, they would fill it up and say they were Christian. Betty certainly wouldn’t, she would put ‘agnostic’. And our children were brought up to think for themselves. In fact my elder daughter, Karen, who died, when she married she said she really wanted to marry in church. In
fact she applied to get married in Worcester Cathedral on the grounds that that was the church
that she had spent most time in. That was because the school that she went to occasionally went
to services in the cathedral, so she never went to church apart from that. Lin definitely has no
religion, basically she isn’t religious. And I can only think of one lady I’ve been involved with
who was Jewish, later on, and that proved to be a problem. In fact it was one of the reasons why
we didn’t stay together, not that we’d been together for very long, but we didn’t stay together.
But, as they say, a lot of my friends are Jews. I do know quite a few, I get mixed up with them
and quite often they do not understand my attitude, not that it worries me.

[49:20]

You mentioned that you remember the Black Shirts as well from the East End in the thirties. What
about them?

Well, in the late 1930s from say, 1935 on the East End became really almost a war zone. It was at
a time when Mosley’s Black Shirts were actually proving quite a potent political force and the
East End was one of their centres because it fed on deprivation, basically, although Mosley was
not deprived. And we did find that some of our friends were actually anti-Semitic in that sense.
I’m not sure they were anti us, but they were anti the idea of Jewishness and the geography of
Diggon Street where we lived was that at the north end – I suppose it was the north end of it – it
opened out on to Stepney Green, which actually was a green area. It wasn’t big enough to be a
park, it was a grassy area, and it was an area where public meetings could be held and it was quite
common for there to be a meeting, I suppose the Communist Party would have had meetings
there and the Labour Party and even the Conservative Party. I shouldn’t have thought that there
were many Conservative votes round there. But the Black Shirts did come occasionally to have
meetings and certainly by 1936 there were quite a lot and if you look into the history books at the
time you will get things like ‘They shall not pass’ and things. And the whole area was quite
divided between the Black Shirts and the anti-Black Shirts and that would actually mean fighting,
I mean there’d be meetings and the Black Shirts would be protected, but they were always a
minority. And the communists would be attacking them. Things would be thrown and people
would be chased. So I can certainly remember shouting at meetings and I can’t remember
throwing anything. I was probably too well brought up to throw things, but others will certainly
have thrown things and certainly bigger boys will have chased us down Diggon Street into our
home. Yeah, it was an exciting time. 1936 I remember, but I could be a year or two wrong, but
that I think is about that time. And it went on for some time. There was considerable sympathy with the Nazis.

*Did you ever get worried by it as a child?*

Well, I didn’t like the fighting. I didn’t like the idea that somebody didn’t like me who I possibly didn’t know and would shout things at me. I didn’t like that, no. Worry, I don’t know that I ever worried about it. No, I don’t know that I ever worried. It was part of living. I’m not sure as a child you do worry quite in that way. You worry more about your immediate family, as to whether something is happening in your immediate family, but worrying about things outside, I don’t think so, no.

*I think we should probably take a break for lunch as it’s…*

Good God, is it that late already?

*Doesn’t time fly?*

[end of Track 1]
I was wondering if we could talk a little bit about you, your schooldays as a separate topic.
We’ve mentioned it a little bit, but…

Okay, school. I’ve mentioned George Bennett – I never called him George of course, it was Mr Bennett – and I was in touch with him, as I said, for many years afterwards we exchanged Christmas presents. And I didn’t get on very well with him to start off with, because I should say that my handwriting was awful. Now, you will not know about handwriting, but handwriting was very important in those days because you did everything with pens and you didn’t have fountain pens either. What you had on the desk was an inkpot and you dipped your ordinary pen with its nib in the inkpot and then wrote with it. And you asked, I said I was quick, and I was wondering what the example was of me being quick. Well, this is an example of me being quick. I was too impatient to write down the answers to the questions. I suppose this came from the certainty that I was right, which wasn’t always true of course. But I was very quick to write things down, so I would dip my pen in the ink and then immediately write down the answer and what I did not care about was the fact that there was an ink blob trail going on the paper from where I was writing to the inkpot, whereas Mr Bennett was not very happy with this inkblot trail. And when I first moved into his class he gave me the cane for it. I still remember that. You put your hand out and he hit it with a long cane, but then he realised I think quite rapidly that this wasn’t something I could solve and that basically he had to put up with the fact that my handwriting was very bad. And it soon developed to the stage which I think showed he was pretty far-sighted. There was another chap in the class called Jack, Jack Randall, we were very good friends. And effectively, I would think by the time we were ten, we were sitting together at the back of the class, essentially with him handing us work to do while he would go on teaching the class and we had very little to do with it. There is a… a little story I could tell you about this afterwards which actually goes back to Senrab Street School and before I was sitting at the back with Jack. When I was coming back from a conference in Japan and was going to, I think it was Swansea where there was a conference, and I was sitting at the dinner at the top table, I was the invited speaker, sitting at table and somebody said, ‘Oh you’ll be sitting next to Mr Goss’. I said, ‘Who’s Mr Goss?’ And they said, ‘Oh, he owns the biggest department store in Swansea’. So I said, ‘Oh, that’ll be interesting’. So I went into the dinner and sat next to him and before I could start talking he looked at me and said, ‘Do you remember me?’ I said, ‘Have we met?’ He said, ‘Oh yes, yes we have met’. I said, ‘When did we meet? I don’t remember’. He said, ‘Oh, it was many, many
years ago’. He said, ‘Don’t you remember the name - Goss?’ ‘Goss, Goss, Goss’, I said, ‘Oh my God, not Leonard Goss?’ He said, ‘Yes’. ‘What, from Senrab Street School?’ He said, ‘Yes’. I said, ‘Well, we used to sit next to each other’. He said, ‘Yes, that’s the point’. I said, ‘Well you vanished’. He said, ‘Yes, and you were the reason’. I said, ‘Well how was I the reason?’ He said, ‘Well’ he said, ‘whenever there was a question being asked, I mean whenever the teacher said, Who can answer this question? You would put your hand up and immediately would answer the question and I was always left out and I was getting very depressed and my parents decided that I couldn’t go on like this so they took me away from the school and put me in a different, in private school’. I said, ‘Well, and now you own a department store’. He said, ‘Yes’. I said, ‘So really you should be grateful to me, you haven’t done too badly have you?’ He said, ‘I suppose you could look at it that way’. And there was he… [laughs] I thought, life is funny, here was Len Goss who I’d depressed years earlier and now he was earning ten times as much as I was, but no, no, he was a very nice chap, very nice chap and he proved to be a very nice man. So I don’t know how we got on to that. Oh that was Senrab Street School.

*What was the…*

[05:20]
But I think perhaps Mr Bennett realised that it wasn’t a good idea to have me and Jack sitting in the front answering all the questions, it would be better if we were at the back getting on with our own thing, so we did. And I don’t think there was any question that we were going to get what was then called the eleven-plus. So we took the eleven-plus, you couldn’t take it any earlier, we took it at eleven and we both got admission to Raines Grammar School, Raines Foundation Grammar School.

*Was it a big deal taking the eleven-plus?*

No, not really because everyone said we were going to get through, it was a question where we came in London rather than anything else. I think actually something about, I think I came top of London in something or other, French or something like that. It wasn’t really a big deal. It was only a big deal if you were going to be borderline and then it was an extremely big deal as to whether you went to a grammar school, and I had an argument with Anne lately on what was the alternative. I thought it was central, but she says no, the name was not right, it was something else that you went to.
Secondary modern?

Yes, I’m not sure it was secondary modern then or whether that came later. The Education Act was changing things round, we’re talking about 1936 now where things were changing a lot and where there had been acts passed earlier which were now coming in and London wasn’t necessarily the same as other centres and even boroughs in London. I think London was being handled centrally by the LCC. But Raines was a school of some standing. You didn’t have a uniform in the sense that there was a proper uniform, but you did have badges on your caps and there was a blazer, not that everyone could afford a blazer, but you certainly were supposed to wear a cap with a metal badge. It’s now very proud of its history if you look at it and you will find me mentioned on their website, which is something that surprised me, I must say, because I never got on terribly well with the headmaster who was called A Wilkinson Dagger. Mind you, he perhaps was a little bit concerned with the number of times that I was outside his study.

Why were you outside his study?

Generally from a disagreement with a teacher as to whether I was contributing to the education of everyone or was inhibiting their education. I would find funny sides to everything that was going on, even though they weren’t that funny. I can remember - I did mention Jack, Jack Randall, whose name may come up later, because he had a very interesting history – but we were together and we often had what were supply teachers coming in and I can remember one who actually was teaching us history I think, would come in and say, ‘Randall in the corner, Hilsum outside the door’. And I would say, ‘We haven’t done anything’. And he would say, ‘Not yet, not yet’. And the next time it would be Hilsum in the corner and Randall outside the door. So I have to say that I was not a model pupil, nor was Jack, because we both had overdeveloped senses of humour I think. I mean we knew we could get on okay and weren’t too worried and we overdid it, but then we were twelve or something, what can you say?

What sort of things did you do?

Oh, silly things, silly things. Talking of course to each other when we shouldn’t. Flipping bits of paper at other people who we thought were being too attentive or were trying to make a name for themselves. There are all kinds of things kids can do at that age that sort of tend to stop the
smooth running of the class. I’m certainly not proud of it now, but then it just didn’t occur to us, we just thought it was funny. I don’t know that that ever stopped actually, because I can say that at one stage in the sixth form we were taking an examination and we should by then have been responsible citizens but when we saw the subject, the essay which I remember was ‘Bells’, we thought how can anyone write an essay on bells, and we decided that the thing to do was the whole class should, the sixth form should go on strike and not write the essay or at least not write a proper essay. This was not a public exam, it just was a terminal exam or something. So we got most of the class agreeing by whispering among each other, because nobody wanted to write an essay on bells. There was one chap who insisted he was going to write it, so I think I said something to his neighbour, well I shouted across the room to his neighbour, like ‘Stop that chap from writing’ but I didn’t use the word chap. And this did not go down with the authorities, so the whole sixth form was kept in to repeat the essay on the next Wednesday afternoon, which didn’t make me popular at all, because there was supposed to be a cricket house match that day and I was in the cricket team and we lost, but I don’t know that we lost because I wasn’t playing, but I was blamed for it. So I can’t say that I ever really was a model pupil. I could say it and of course there’s probably no-one still alive who can say nay to that, but I have to admit that I did waste a lot of time and probably other people’s time, now I would think, instead of my own, because you don’t consider what is happening to other people when you are twelve or even then when I probably was, I suppose seventeen. An unmitigated scoundrel, I think you can say.

[12:40]

How do you think your contemporaries saw you in school?

Hm?

How do you think your contemporaries actually saw you in school?

We all got on all right. I got on very well with Jack and no, we all were okay. It wasn’t, there wasn’t any bullying or anything like that that I was conscious of in our school. I only can remember once and that was not at Raines, at Senrab Street, getting in a fight with somebody. I can remember getting in a fight with a rather fat boy and I was punching him and nothing seemed to happen. It all seemed to just soak in and he was punching me but he didn’t seem to punch very hard. And in the end I think the kids around decided that this was a fight that was going nowhere, so they separated us. And I can’t remember what it was about, I can remember punching him and
him punching me back. I don’t know what it was about and it never happened again. In the end I decided this was not a suitable thing to do so I avoided fisticuffs and instead learnt to run faster. So when I would make a jibe at somebody and they’d take offence, I would turn on my heels and run away and actually I learnt to run faster than I could fight. There’s probably a moral in that somewhere to someone. I don’t know.

*What was Senrab School actually like? It’s a curious name for a school.*

Well, I’ve said how the name came about.

*You haven’t said on tape actually.*

Oh, haven’t I?

*No. We discussed it…*

Oh, well the name came – and I only learnt this a few years ago – from a councillor called Barnes and the name is the inverse of his name, just turned back to front. I don’t know why he didn’t want it called – it was named after a street, obviously and Senrab Street I think still exists and sounds a bit Oriental or Indian, but it isn’t, it’s Barnes backwards, and he was a councillor and I presume he got bored with having things named after him called Barnes this and Barnes that, so he decided to work a change and called it Senrab. But I think very few people would realise that the word Senrab actually is Barnes backwards. Because it sounds somehow right, but of course it isn’t. Well, it was the school that all the kids in the street went to, it was probably about 300 yards, three or 400 yards from home. It was near Commercial Road and I can’t remember going there, but I presumably walked or when I was young pushed in my pushchair there. I can remember some of the teachers who seemed quite good. There was, as I’ve said, George Bennett. There was Mr Evans who ran the class below that. I remember when I was put up into his class I think I was probably about eight, by then I was a bit ahead of my time and I can remember I’d found life pretty easy with work, I mean things were not difficult to do and we had an exercise to do and it was addition and I added everything up and when it came back everything was marked as wrong. And I really couldn’t understand this as to why everything was wrong because… and I took it to him and said, ‘Well, what’s wrong?’ And he said, ‘None of it is right’. And I said, ‘Well how can it be wrong, I’ve added the things up’. He said, ‘Well you’ve taken no notice of
the decimal point’. And I said, ‘What’s the decimal point?’ He said, ‘It’s there’. I said, ‘Oh I saw that, I wondered what that was’. And he said, ‘Haven’t you done decimals?’ I said, ‘No, what’s decimals? I’ve done sums’. And he said, ‘Oh. Oh’. Because I had missed the class, I had been put over a class, and put there, and I was really very upset about this until he pointed out to me what I had to do, and then it was okay and he was quite sympathetic. More than George Bennett was with the blobs, I will say.

Why does George Bennett stick in your mind as a teacher?

Because he was so nice to me. I mean basically, he – I could actually, I’ve probably got…

Pop this on pause for a second.

[break in recording]

[17:50]
A report he wrote for my parents, which basically said that they should know that I was going to go far and they should ensure that I did. And he was the first person I think who really showed confidence in my ability. The others took it for granted, they never said anything but he was the person who focussed, the first person who focussed on the fact that I did have some ability. And I mean basically he insisted we kept in touch afterwards and I did keep in touch with him for something like, probably twenty years. Long time. And it was the same with Jack, I mean he put us together because he knew we could feed off each other, and we did and we had competition and sometimes I did better than Jack did and sometimes Jack did better than I did and we had similar views on life, similar backgrounds, though I think actually Jack’s family was probably a bit more prosperous than mine was, not a lot, but slightly more. [19:20] Well, let me get to eleven-plus, and we went to a school which clearly was different. There was more competition, it was obviously more structured, you no longer had a form master in the same sense and the masters wore gowns. I don’t know what I can really say about Raines School.

Were you competitive? You mentioned it got more competitive, did you…

Oh, I’ve always been competitive, yes. It’s a great fault in there, everything is a competition and that certainly goes back to your roots, that you knew that you had to do things for yourself and
had to do things better than other people did otherwise you’d just get swallowed up in the morass of life in the East End of London, which you certainly didn’t want. The only question was to choose which way you went. And you didn’t have any models, that’s really the problem, that… you didn’t, nobody in any of the families I knew had ever been to university and indeed, my ambition was to work for the LCC because Charlie had got a job with the LCC. I knew that – I’m jumping some years, so this is going to seem a bit odd, but we can go back later on if necessary – I was going to stay on in the sixth form. I have jumped over the years when we get evacuated, and we’ll come back to that, but it is part of the story in that in the sixth form I was going to stay on in the sixth form and do not my A levels, but an LCC examination. And that was quite interesting because the LCC examination was actually broader than A level, more subjects, though perhaps not at such a high level. And Charlie had got into the LCC, though by now Charlie was in the army, and I thought, well this is a good thing to do. And I think it was the geography teacher who said I don’t understand why you’re doing this strange mixture of subjects, which I remember was five subjects, because I was doing physics – I wasn’t doing chemistry and I’ll come to that later on – physics, pure maths, applied maths, English and French. Now, that’s neither science nor arts, right, and why was I doing this? Well, I was doing this because that’s what you needed for the LCC exam and the geography teacher said, ‘But why don’t you go to university?’ And I said, ‘What’s university?’ and he explained and said, ‘You really shouldn’t go to the LCC, you should go to university’. I said, ‘Well okay, I’ll take the same subjects and go to university’. He said, ‘No, you can’t do that. You can’t do English and French at that level and the other subjects, you have to have four main subjects and you can do the others as subsidiaries’. I said, ‘Well, I haven’t got four main subjects’. And he said, ‘Well, you could do geography’. He said, ‘You were quite good at geography for your ordinary matriculation’ which is what we took, ‘You did that quite well’. I said, ‘Well, I’ve only got a year to do it’. He said, ‘Oh you could do that easily. If you work hard, now I’ll give you some things to do’. I can remember it was towards the end of the summer term when I was going to be seventeen. He said, ‘I’ll give you some things to do’, we were evacuated at the time, ‘if you like to work hard at it you can get up to the right level certainly by the beginning of the next term and then you’ll be the only one doing geography at this level and I’ll concentrate on you and I’m sure you will be able to get through’. So, I said okay, so that’s what I did. So I finished up as probably the only person doing physics in the world who did geography at A level, but as I pointed out to somebody later on, at least I knew where the conferences were being held, whereas most people didn’t. I knew the capitals of all the countries, so I did geography and that’s what I did, I did pure maths, applied maths, physics and geography for A level. And that’s how things happened and it was all because nobody I knew had
been to university. And it was the same with Jack, but again, nobody he knew had been to university. He was in a different situation, as we’ll come to later, which is a bit strange, but that’s how it all happened. So we were at Raines and doing the things that kids do between eleven and fourteen.

[25:40]

What do kids do between eleven and fourteen in 1940s?

Well, I had very little choice in the subjects. It was a pretty broad degree of subjects. I’ve said how untidy I was and this proved quite a limitation and did in fact determine some of my choices later on, because I didn’t get on well with technical drawing. Technical drawing was something, was a subject, nor did I get on well with carpentry, which was another subject which you had to do. I used to do joints, I mean now they do technology or something, but then we did woodwork. Why I did woodwork, I do not know, but woodwork was one of the subjects you had to do. And I was always too impatient, patience is not one of my virtues as people will tell you, and I used to carve the joints and then they didn’t quite fit so I would then put sawdust in them to fill up the gap and the master, I remember his name was Nay, Charles Nay, he would look at my joints and say, ‘Well this looks very good, very good Hilsum, very good. Mm, it’s not pushed quite home’. And he would bang it and when he banged the joint of course all the sawdust would come out and he’d say, ‘Oh it’s not quite as good as I thought, it doesn’t seem to fit terribly well’. So my mark would go down. But I, I mean you had to take it, it wasn’t terribly serious. Similarly, in technical drawing I was never very happy with being neat and the technical drawing master who claimed to be an engineer, and he probably was, his name was Andrew – these things come back to me – his name was Andrew or Andrews, he was a grumpy person and I still remember giving him my drawing, my technical drawing, and he just dropped it on the floor and said, ‘Rubbish’. And I was really quite upset about that because I’d worked quite hard at it. He didn’t seem to understand that these things don’t always come naturally to people. So I did try, but I was never quite able to master it. And similarly in chemistry. We used to do drawings which showed water in flasks and the way you showed water in a flask is you obviously have a horizontal line that’s the top level of the water and then to show there is something there you put little dashed lines across the level going down and you have them staggered, so you put in four or five dashes on each line for the flask of water. And I was always so impatient with putting these in – this was usually done in pencil – and I was so impatient that my dashed lines always showed a little curl upwards at the end where I took the pencil off the paper and went on to the next one. But I could
never sort of do a regular series of dots. So the chemistry master always objected violently to my drawings. And I could never understand this. I would always argue with him, saying, ‘Well, is this drawing or chemistry?’ And they’d say, ‘It’s chemistry but it has to be presented properly’. And I would say, ‘That’s art. The chemistry, there’s nothing wrong with the chemistry is there?’ And they would say, ‘There’s nothing wrong with the chemistry but I’m marking you down because of the presentation’. I would say that’s unfair, it’s not fair. That was another thing I used to say, it was one of my catchphrases, ‘It’s not fair’, and they used to get very bored with me. So…

**What makes a bad technical drawing?**

Oh, fingerprints on it, over it, lines being not absolutely straight. A variety of things can make it not a very good technical drawing, but generally it was presentation, that I was always sloppy. It was a question of getting it done quickly.

**Why were you in such a hurry?**

I wanted to get on to the next thing. I mean I’d done this, I could see it, I could see this now, I’d sort of completed the intellectual part and it was done, it was a drawing and I could see what you had to do in the drawing so I wanted to draw it quickly and then get on to the next drawing, or whatever it was. I wanted to accomplish more in a finite time. I don’t know why. Not in that sense, it was always you wanted to get on with things and do them quickly.

[31:10]

**What do you think your favourite subjects were at school, if not technical drawing and carpentry?**

Well, early on maths, I was very keen on maths, in various ways. I could do it and I liked doing it, I liked playing with numbers, I liked the more advanced things later on with geometry and then conic sections and all that kind of thing, I found that very good. And then obviously I began to like physics. I mean I liked the arithmetic in the elementary school, but once I got to secondary school, the grammar school of course, we got into physics and I liked physics. I quite liked chemistry, but at one stage – and this can have been specifically towards the end of being fourteen, no, when I was fourteen, this would have been the third year, I had to make the choice
and the choice that you had to make was either geography and economics or chemistry and technical drawing. Now, don’t ask me why there was that choice. If the choice had been chemistry and economics or geography and technical drawing, I would have gone chemistry, but I couldn’t do technical drawing for the reasons I’ve said, and I wanted to do economics because I thought this was going to be an interesting subject. So I voted for geography and economics and that was down there and I was going to be in the class to do it. Now that was 1939 and in September of course things happened, we were evacuated and, would you believe it, Andrews retired, so technical drawing was taken off the agenda and the economics master was called up. So, I had now chosen geography for completely inadequate reasons, but I had chosen geography instead of chemistry. Well, that was ridiculous and the fact remains I did geography for my GCSE and did pretty well on it, but of course the others who were doing physics and maths were doing a much more normal course, because they were doing pure and applied maths, physics and chemistry. This affected me later on in a way that could not have been foreseen, because when it came to do a Cambridge scholarship, which I did, I could not take a natural sciences scholarship because I couldn’t do chemistry and the only thing I could have done was an engineering scholarship and I hadn’t done any engineering, so I had to do maths. And they used to say if you could pass a Cambridge scholarship in maths you didn’t need to take the degree, because you’re already at that standard. And in fact when I came to look at the questions I did, actually did maths with a physics subsidiary and they told me I had passed in physics but I had not passed in maths. I was not surprised, I think I could only answer two out of the questions, I didn’t even understand the questions, never mind answering them. But the physics was all right. Physics was interesting because one of the, I can still remember one of the practicals that they showed you, which was you were given a disc and they said the disc is magnetised, you are given a piece of string, find out in which direction it is magnetised. So I soon worked out that the thing you do was to actually suspend it and you mark a line on it and then you turn it over and you get your line going two directions and you halve them and then it’s a question of working out which way is north and which way is south. Well, I had done this and worked it out when a gentleman came by and said, ‘How are you getting on with that experiment?’ and I said, ‘Oh, it’s quite easy’. And he said, ‘Oh, how do you do it then?’ So I told him how to do it and he said, ‘Well how can you tell which is north and which is south then?’ I said, ‘Well normally you would judge by the light outside as to where the sun is’ I said, ‘but’ I said, ‘actually here it’s much easier and in fact you don’t need to do the experiment’. He said, ‘Why not?’ ‘Because on the roof here you’ve got magnetic north, there’s a big arrow there and it points to magnetic north’. And he said, ‘Oh my God, oh my God, I did not know that was there’. This was one of the Braggs, I
think it was the younger Bragg, later had done this. But that’s a fact, I mean many physics labs had at that time on the ceiling an arrow showing – a big arrow, not a little arrow - a big sort of sign that showed you where north was and where magnetic north was and there it was. Mind you, you’d only have passed if… you couldn’t possibly have passed then, I looked up at the ceiling and it showed me which was north, actually even if you knew which was north you wouldn’t necessarily know which it was on the disc, but you certainly would know which was north and which was south. So, as a result of this, I’m telling you this story because it shows how my life changed simply because of this choice, which was completely inadequate, in doing geography rather than chemistry, which does come later on, no doubt on about our fourth interview when we get to 1972. But okay, it didn’t matter, I was going to do physics and in fact, well, in fact I took a scholarship to UCL and got it, but that comes later.

What did…

[37:45]
So, now we get to 1939 really, when we were evacuated.

Where were you evacuated to?

Well, that’s again is really intriguing when you think about people. We were obviously in the East End of London and we had our gas masks and things and the whole school was evacuated to Brighton. Now, it doesn’t need a genius to realise later on that you’ve actually put these children nearer the enemy than further away. But that realisation happened of course the next year when the war did not go terribly well and they appreciated that now we were probably in a more dangerous place than London. London hadn’t quite been bombed then. So, they said we’ll have to re-evacuate them. In fact I think they were evacuating the Brighton schools as well, so we were there and it was completely inadequate. Evacuation was quite interesting because the first billet – we were billeted on people, I mean what happened essentially is you were put with people and this was completely voluntary, people could apply to have evacuees and they were paid, but the first people we were put with weren’t terribly interested in the money, he was a councillor and he thought it was his duty to actually take people in and he and his wife and daughter were very nice to us. He owned a baker’s shop in Ditchling and that was okay, but they were quite mature. The daughter was grown up and they’d a bit forgotten about how you fed young kids, so we were fed on quite a lot of pastries from the baker’s shop, which I will say as small boys – well, I wasn’t
that small then, fourteen – we thought this was great, I mean lots of cakes. We had cakes for our pudding at lunchtime, we had cakes obviously in the afternoon. We thought it a little bit odd when we got cakes for breakfast, but we didn’t mind, I mean that was okay and I don’t suppose it would have done us much harm. But after a time they thought this was not really appropriate so we were put in another billet, it wasn’t terribly far away, it was in Stanmer Park Road, with a man who, he was very nice but quite stern. His wife, they obviously were doing it for the money and it was okay there. The only problem we had was with the daughter of the house who was ten and couldn’t quite see why we were treated differently from her in bedtimes and things like that.

Well, it’s true that there wasn’t that much difference between her and Sid – I should have pointed out obviously that Charlie now wasn’t there but I’d gone with Sid and we were together, obviously, and stayed together – Sid was twelve and a half and I was fourteen and there was a great deal of difference in our attitudes between a girl of ten and a boy of fourteen. But she was insistent with her mother and so we were forced to adopt her bedtime and things like that, which didn’t go down terribly well and there was a considerable stress generally in the household between her – her name was Sheila, I remember that now, that comes back to me. But we got on very well with the little boy in the house, they had two children and he was a nice little boy. So for the next ten months, suppose it was – it may not have been quite a long as that, I’ll have to think about dates, but it probably was a bit like that - there was a bit of stress in the household. I’m not saying there was anything wrong with what they were doing but the mixture didn’t work out terribly well. But we were evacuated to a school called Varndean, which is a well-known school, not quite a public school, but I think it was pretty well known and was quite a high standard. I’m not sure how the classes were arranged, I know how they were arranged at the next school we went to. But I don’t remember much about the lessons there. [43:10] I do remember that probably… get the months right. Probably after we’d been there about nine months it was decided that we ought to change our billet and we were moved then to a very, very poor household with the Campbells in the lower part of Brighton, quite a way from Ditchling. And these were people who really needed the money from billeting and they were lovely. I mean they were such kind people, it was such a kind household and they didn’t have two pennies to bless themselves with but they looked on us as not quite on their level, as somebody they had to live up to, and they had to look after us. And the problems we had were in actually eating all the meals that she was putting in front of us. I still can remember that they had what was a range, it wasn’t an Aga, it was a range and there was an oven by the side of the coal fire and she cooked us a bread and butter pudding – no, it wasn’t a bread and butter – it was a bread pudding, in a dish – I can show it to you but that won’t come through on the tape – it must have been about eighteen
inches square, it filled up the range and she made this and said, ‘You boys have to eat this. When you’re hungry in between meals you must have some of the bread pudding’. And after three days she said, ‘What’s wrong with my bread pudding?’ And we said, ‘Mrs Campbell, there’s nothing wrong with your bread pudding’. She said, ‘But you’ve only eaten about a quarter of it’. And we said, ‘But you feed us so much’. And she said, ‘Nonsense, nonsense, you’re growing boys, you must eat more’. I can still remember, we used to go home at lunchtime for lunch. Now, Ditchling is up higher than the bottom of – we were underneath the viaduct there, somewhere down there, and it was okay walking down there, we were young so we could walk quite fast, but after we’d had lunch we had to walk back uphill and Sid and I, we really had quite problems in actually coping with it because she used to feed us so much. But we were only there for a couple of weeks before we were re-evacuated. But she, we said she had to write to us and I will say that the letters we got from her were heart rending because it was so hard for her to write. You could see that she had a problem in actually writing, it wasn’t just the wording of the thing, it was the way she formed the letters, she’d had very little education and it was so sad. And yet, we still remember her, I’m sure Sid still remembers, I certainly do, the time we had there because it was such a contrast to the three digs that we’ve had. The one with the councillor with pastries, the next one – I forget their name – but in Stanmer Park Road with the problems we had with Sheila and what you might have thought as a normal family and then suddenly being plunged in this and certainly we had come from a poor household, but we didn’t know what poverty was, not until we went there. And seeing how they lived and, oh, oh well. I don’t know what’s happened to them because we obviously lost touch because she didn’t answer the letters after a time. We did write because we were very fond of them. [47:35] And then suddenly we were told we were going to be re-evacuated and we had no idea where we were going, but in the end we were placed in a place called Camberley. Now again, it beggars intelligence to think of who could actually do this. Now, the first mistake they’d made was putting us nearer the enemy in Brighton, the second one, Camberley is exactly halfway between the Royal Military College in Sandhurst and the Royal Aircraft Establishment at Farnborough, almost exactly halfway. So it’s not terribly surprising that we were occasionally bombed. I mean, it was ridiculous. I personally was bombed. Bombed, yes, personally. I was with Sid at the time and we were walking at night home from something or other that we’d been to, some club on our way to our home, and a German decided he was going to drop four bombs on us. Actually, I say dropping four bombs on us, almost certainly he had been intending to bomb either the Sandhurst Military College or Farnborough Royal Aircraft Establishment, but he hadn’t been able to find them so he was going to bomb me instead, and Sid. So he dropped four bombs. They were probably about 200 yards
away, maybe 300 yards away. They fell in a field, just… But we were sure he was bombing us, that’s what we told people, he was bombing us and only just missed us. He missed us by a long way actually, but still. But it was really an odd decision to put a re-evacuation there, if you’re re-evacuating people you don’t put them in a place like that. So then we were with Mr Way. Mr Way was a widower who had a son, I think his name was Edward, and a daughter called Winifred who did not live at home. Edward worked at the Royal Aircraft Establishment, he was some kind of apprenticed engineer. There was a housekeeper called Miss Peters and Way was always called Pop, Pop Way and he worked at Sandhurst. They always cycled, both of them cycled to work. And we walked to school across fields after a time. First of all we were at the local grammar school and we did our practicals there, but we had to stagger them because it couldn’t be done at the same time as the main school, so the whole thing was staggered. And after a time a house, the school either bought or more probably rented a house in Brackendale Road that was about fifteen, twenty minutes’ walk from where we lived so we walked there and that was quite pleasant there, and we had classes there and that was, I suppose, let me think, fourteen, fifteen… We certainly did our matric there and then stayed on to do – I’m trying to think how… I don’t think the whole school went there, I think this is the point, I think some of the school went to Egham instead, I think the younger classes went to Egham. They can’t have been much younger because Sid certainly came to Camberley. And Camberley was quite a nice place to be with and the school did all they could to give us entertainment and keep us out of harm’s way, which they did mostly. That’s where I learnt to do ballroom dancing. They even arranged classes for us with a lady called Monica Marshment, I can still remember that and as someone said, ‘Her legs went up to the ceiling’. And she was a very good teacher and gave us all a good grounding in the four basic dances, which stayed with me for many years, in fact I still can do some of the steps. But it wasn’t modern, we didn’t… she didn’t do too much on the tango, which was a shame because I needed that later on. And she certainly didn’t do the other dances and she taught us to despise the group dances like various waltz and things. And we had – oh, I remember there was somebody who gave us private lectures on insects and I learnt about insects and butterflies and things, in his home. And generally it was quite educational.

[53:10]

Do you think that the experience of being evacuated broadened your horizons at all?
Oh, it had to, yes. I mean yes, there was no question of that. It certainly broadened your horizons in learning about people and in being quite cynical about some people which I think a lot of my friends and acquaintances will say has stayed with me all my life, yes.

Why cynical?

Oh, certainly the first thing with the councillor who was quite happy to have us for a time as a symbol of what he was doing for the community but when it proved awkward he decided that maybe he’d made his gesture now. I think it was only about a month before he decided that he’d now made his gesture and – I think it was his wife actually who said this is all too much, we can’t have these two young boys around, I haven’t got the time to look after them. So yeah, you can say it’s a bit unfair, but that sort of made me – and the comparison between the three homes, I probably wasn’t aware at the time of the sort of impressions I was getting or what I was doing, and other things happened, which we’ll come to in a minute. So yeah, these things wouldn’t have happened if the war hadn’t happened, but well that’s true of everyone isn’t it, what can you say? Now, Pop Way was another thing. Now, I do not know what his economic situation was and it could have been that he was actually short of money and was concerned about expenses, but he would come in when we were doing homework and say, ‘Why have you got the light on?’ And we’d say, ‘We’ve got the light on because it’s dark’. He’d say, ‘It’s not that dark. You’ve got young eyes, you ought to be able to read’. And he turned the light off. We’d say, ‘Pop, we can’t see’. ‘Oh, well just concentrate a bit more or go over nearer the window.’ And then, I certainly remember on one occasion, he said, ‘You boys are using a lot of toilet paper aren’t you?’ And we’d say, ‘Well, yes, yes, but what are we supposed to do?’ Now, actually the toilet paper we were using was imprinted with ‘Royal Military College’ on it, so he was getting the toilet paper and he thought we were using this too fast so he needed to bring some home. He said, ‘Can’t you bring any from school?’ And we said, ‘Well, we don’t like to sort of bring the toilet paper from school’. He said, ‘Well’, he said, ‘really you’re using the toilet paper so you should provide the toilet paper’. Well, somehow we got round that, I don’t think we ever did. And he would do things like that. But then, bombing started in London and he insisted that mum came down and stayed with us. He said, ‘You can’t have your mother up there in London, it’s too dangerous. She’ll have to come and live with us.’ I don’t know how the accommodation worked, but there was no question she came down and it’s no question that she did not pay for accommodation. So what did I learn from that? That people are complicated. It was extremely generous but at the same time he was worried about the lighting and the toilet paper. How can you bring those things
together? I don’t know. Okay, what was happening in London was dad became a light rescue man. [57:25] He basically obviously wasn’t one of the heavy rescue people, he wasn’t built that way and of course he was getting on. Let me think. He must have been in his late forties by then, he was born I think 1898 or something like that, I think that would be about fitting. Might have been a bit earlier than that, yeah, must have been a little bit earlier than that because he was called up in the first war. So he probably was in his fifties and he wasn’t eligible for military service so he volunteered, as people did, for the various air raid precaution things. And there was light rescue and heavy rescue in the Blitzes. And the heavy rescue would really move large bits of houses where the light rescue would essentially try and get people out of buildings and see to them, and of course we come back to his qualifications in first aid and home nursing, so he effectively could act as a person who could see to the slight injuries or the first injuries, obviously he wouldn’t deal with anything that needed real medical attention but he could certainly deal with broken bones and simple bleeding and things like that, so clearly he could fulfil a function. But there wasn’t much mum could do in London and the East End in particular was pretty heavily bombed, they would go down the Tubes, well, mum would go down the Tubes. Charlie was called up of course and wasn’t there, and in the end the house was bombed. So I don’t know at what stage they found the house in Streatham. I don’t think it was that difficult to find housing, a lot of people had left London because of the general bombing. So dad would be working in the East End anyway at first and mum was down with us and then later on they I suppose moved back to Streatham, I don’t know of the exact details.

Does being evacuated affect your schooling much or is it the same bunch of people just in a different school somewhere else?

Well, it was the same people. I mean the teachers were evacuated as well, we had entirely the same staff except for those that were called up. Now that was interesting. I said that we had a very good history teacher called Mr Bence, I can remember him. I remember what he looked like. He was quite young and he was not called up because, as I recollect, he had a gammy leg; he limped, I can remember him limping. Now I don’t know why he limped and it never occurred to me to think it at all strange. Now I realise that he was there still doing history because he wouldn’t have been eligible for military service. And he was excellent, he gave me a taste for history that has never lapsed, I’ve always been interested in history.

What did you enjoy about history at school, with Mr Bence?
Again, it was an account of what people did and why, the logic of actions. Why did we go to war with Germany in the First World War, we had so much in common. And he told me about control of the mouth of the Rhine. Now, the mouth of the Rhine had never occurred to me as being important to me, but he pointed out that the British had always considered as a fundamental point that a large country should not control the mouth of the Rhine, it was too important to the UK and they were happy while The Netherlands was in control, but there was no way they were going to leave Germany in control of the mouth of the Rhine. And I can still remember there were twelve reasons why the UK went to war. And the analysis was excellent. Now, they don’t teach history like that in schools now any more. And we mostly dealt with British history, but we did deal to some extent with European history as well, and Napoleon and things like that. I found that very interesting. Actually, I found most subjects interesting, that were intellectual subjects. That was okay. I could also deal with languages reasonably, though my French and my German both had a pronounced Cockney accent. I didn’t realise I had any accent until I went to college, when people pointed out that I had a very – nobody had ever pointed out to me that I spoke French with a Cockney accent, but I did. The French told me that later on, as did the Germans. But I – that’s one of things of course evacuation did for me, that I did not appreciate, was that I gradually lost my Cockney accent. There still are some traces of it, I’m told, but I think I could pass for more or less anything now.

[1:03:20]

You mentioned that you enjoyed, you know, physics as well. Why, what was the attraction at school?

Well, physics of course was following on from my interest in how things worked and taking them to pieces. Also the mathematics of physics appealed to me. I was doing pure maths and applied maths and applied maths just went automatically into physics. I was interested in the mathematical analysis you did and wave motions and things like that. At that stage I wasn’t doing the higher maths that was necessary. In fact I don’t know that I ever did. But the linkage of pure maths, applied maths and physics was a whole and that certainly I found appealing and easy, I had no problem in that. I found geography a bit more difficult, it wasn’t as… it was too much a memory thing. My memory is pretty good and was pretty good, but things didn’t appeal to me because of remembering things, that’s possibly why I would not have got on so much at
chemistry. It was working things out. Once you remembered the first steps then the rest you could get through by logic. I think that’s what it was.

_When did you actually return from evacuation?_

There was one step in between that, which again is interesting, again you can think that it was another broadening of me. This was towards the end of our stay in Camberley and I don’t remember why it happened, but essentially there was either a breakdown in relationships between us and Pop Way – mum had gone back to London by then, we’re now talking about, let me think, it must have been almost 1943. Mum had gone back to London and we had to leave our digs. I don’t know why this was, I haven’t really thought about it much. It could well have been that we had had enough of Pop Way, or he’d had enough of us, or possibly the domestic circumstances changed and there wasn’t accommodation for us. I don’t remember why, but it was a fact that we could no longer stay and what is more, it was impossible to find digs for both Sid and I together. So Sid finished up in the lodge of a big house on the outskirts of Camberley. I mean basically there was a lodge at the end of the drive with presumably a lodge keeper there and Sid was there. I was evacuated, I was re-evacuated or replaced in the home of an ex-military officer who was extremely posh. He was extremely posh, he was posh enough so he had his own, I don’t know what you’d call it, it wasn’t a dressing room, it was a cubbyhole, basically. And by now people were being billeted. They were looking for houses and if you had spare rooms you would have a child billeted on you. Well, I was hardly a child by now, I mean I was seventeen, getting on for eighteen, in fact I probably was eighteen, because I’m not sure how long I was there. Yeah, I could have… yeah. And essentially I was stuck on them and they didn’t know what to do with me. So, I was given this little room as my bedroom and I ate in the kitchen with their very ancient maid, Nellie. Funny how these things come out from my very bad memory. Nellie was okay, Nellie was wiry and I don’t think she had an ounce of fat on her, and she was quite old, obviously she had to be old because people couldn’t keep servants then because they’d all be in war work. But somehow they’d got it, they… there was a very posh lady of the house and the gentleman, who I think was a retired major. He seemed all right, she obviously resented my being there, and Nellie was fine and I spent a couple of months there I suppose, under some sufferance and not being terribly impressed. But I knew by now where I was going, [1:09:35] both Jack and I – remember Jack – had been accepted for UCL. We talked about interviews, I can’t remember much about my interview. Jack’s interview was interesting because this was a joint interview for scholarships at UCL and King’s College and I’m not sure whether there was a
written examination. I think they were going on A levels, on what we would get for our – it wasn’t A levels then was it? Whatever it was. And Jack was asked what reading he had done. Fortunately he did his interview before I did mine so he came out and told me what had happened. And he was asked what reading he’d done and he said, ‘Oh did read a monograph, one of the Methuen Monographs, on relativity’. And the chairman got very interested, he said, ‘Oh, oh, on relativity? What did you think of it?’ And he said, ‘Well I tried, but I have to say I couldn’t make head nor tail of it’. At which the rest of the interview board fell about laughing. And Jack looked and said, ‘I presume I’m addressing the author’. He said, ‘Yes, you are’. And Jack should have known actually, because it did say on the booklet – it was Flint, I think, from King’s College – it did say he was at King’s College. But Jack came out and said, ‘Whatever you do, don’t mention Methuen Monographs and things’. I said, ‘Thanks Jack, okay’. I can’t remember anything. Jack did get the scholarship and so did I. Now then you get some interesting points coming up. There are bits I’ve missed out, obviously, but I’m not going to cover all those years. The rules were a bit strange about going into the forces. The war was still on of course, just about, and you had to settle what was happening towards I suppose the end of ’42 when we were seventeen, going to come up to eighteen. And apart from the fact that you could be called up in to work in the mines, and I think it was about a ten per cent chance that you would get chosen, and then you did, so that was it, there wasn’t much you could do. Though in fact I didn’t know anyone who did get called up so it’s possible it wasn’t quite what they said. But then the arrangement was that in that year in which you were eighteen, if your birthday was before January the first, then you were called up. If your birthday was after January the first you could stay on at college, at college provided you were going to do a science degree. And I mean you couldn’t, if you were going to do arts you couldn’t stay on, you just were called up. But as far as the science people were concerned – now there was a throw of the dice of course, and both the Jacks I knew – I haven’t mentioned the third Jack have I?

Or second Jack.

There were three of us who actually were friends. There was Jack Zussman, I think he must have been at Senrab Street School as well, as well as Jack Randall, but Jack Zussman did not go to Raines. He lived slightly further away. I have to work out where Jack Randall lived, but Jack Zussman lived a little bit further away and his parents had decided he was going to go to Coopers’ School, which again was a grammar school, but it was different. So we didn’t know each other at school but we still were close friends. He now was also born in November I think,
so he and Jack were going to be called up. Jack Zussman is interesting because he actually came back, went to Cambridge after the war, got a degree in crystallography, went to Manchester and then moved from physics to geology where he became head of department and became extremely well known for a series of books he’s written on geology, and that was mostly because of course he knew some physics, which most geologists didn’t seem to know. So that was Jack. Jack Randall was going to be called up. Both of them became radar petty officers on ships that were in the Far East and both came back at the end. As I say, Jack went to, he went to Manchester in the end after Cambridge and Jack Randall went to UCL to do physics. Now, Jack Randall was very clever, very clever indeed. He was too clever for his own good. He worked out at college that he could predict the questions that were going to be asked. There is no question that he could have got a first class degree, no question he could have got a first class degree. Instead he decided that he had other interests than studying, but he was prepared to work out what questions were going to be asked and answer those. Unfortunately he got it wrong, so he got a third class degree and I later discovered that – I met him at Portsdown, at the Admiralty Radar Establishment where he was not a scientist, he was in the experimental officer grades and people said he’s far too bright to be an experimental officer grade, but he seems happy, because Jack had discovered table tennis. He hadn’t discovered table tennis in the normal way, he discovered table tennis as an umpire, a referee. And he, while he was supposed to be doing his degree, was travelling around England with the English table tennis team as the referee. And he died a couple of years ago and his obituary was in the papers as the best referee they had ever known, that everybody respected him because his knowledge of the game and the rules and nobody ever questioned his judgement. And I thought, this is Jack, what can you say about people and the way in which they go. So, okay, that was the two Jacks. [1:16:58] I of course was born in May, so there was no question I could stay on and I had taken the UCL scholarship. Cambridge had told me that I was welcome to come and do physics if I could get funding as a bursary. And I did look at that, but essentially you couldn’t live in Cambridge on the bursary, you would need more support. I was pretty certain that I could - I didn’t know where I was going to be going in ’43 - but I was pretty certain that I could get support from a state scholarship. State scholarships weren’t very common but the school was pretty good actually, they knew enough about it and said that Jack and I would both almost certainly get state scholarships through our, whatever our level was, it wasn’t called A level then, it was called something else. It was an advanced level that you took at eighteen, and they said you will do well enough, you’ll get As or top marks in your physics, chemistry and your applied maths, and Jack probably in chemistry. Geography was less likely because I’d only done it for a year. But there will be enough for you to get a state
scholarship, and that’s what happened. Both of us got state scholarships, which was pretty good for the school because I think there were probably only about a hundred in the country.

What did your…

And that gave you £100, which was pretty good then, we’re talking about 1943. And I also, and the school also, probably through the local authority gave us some more, so I think that was twelve pounds we got from the school. So that was enough so I could actually give mum some money for my keep during holidays. And so, 1943 I went up to Bangor. The reason why I went to Bangor was because the college was evacuated. UCL obviously was normally in Gower Street but it was broken up. Physics, French, English, maybe even history, not sure, went to Bangor. Chemistry and German and possibly some other things went to Aberystwyth. Engineering went to Swansea. Architecture went to Cambridge. That’s as much as I know. I’ve missed some things out, but I’ve no doubt bits went elsewhere, but the college essentially was split in that way. [1:20:25] So, I went to Bangor about which I knew nothing at all. I knew where it was, obviously, through my geography. So I went up to an interview there with Orson Wood, who was the tutor to science students, and asked what I wanted to do and I said well, what I want to do is to spend two years doing physics and then one year doing maths as a degree. He said, ‘That’s ridiculous.’ I said, ‘Why is it ridiculous?’ He said, ‘Nobody could do it’. I said, ‘The regulations say you can do it’. He said, ‘I don’t care what the regulations say is permissible, it is neither advisable nor possible. You had better just concentrate on your physics and you do physics with maths subsidiary’, which is, well I said okay, that’s what I’ll do. It’s interesting actually that the person who shared digs with me, Brian Bransden, who I did not know, there I met actually up in Bangor, he hadn’t done as well in his A levels. He’d got lower marks in chemistry I think, so they had decided that he could not do an honours degree in physics. Instead he had to do a general degree in physics, chemistry and maths. And he had to retake his A level in chemistry at Christmas, which he did and got it. He then went on to get a first class honours degree, a first class degree in each of those subjects, which is more difficult than getting a first class honours degree because you have to get first class in each of the three subjects. He then went to Durham, became a professor of theoretical physics and head of department of theoretical physics up there, having not been thought good enough to take an honours degree. Amazing isn’t it? And of course had a great success as an educationalist. I think he died a few years ago, I think he did.

What did you make of actually going to university instead of joining the forces?
I’d never thought of joining the forces, I’m not a warlike person. So… you didn’t think about it. I mean you were constrained on a path, you didn’t make choices. I actually didn’t make any choice in my life until I was fifty-seven, which we’ll come to later on. That isn’t to say that there weren’t things that had to be decided, but everything was obvious. I mean there were three things you could do and one of them was obvious and the other two were possible, so you did what was obvious. It wasn’t until I was fifty-seven that I actually stepped out and made a decision. Yeah, which we’ll come to later, but I can’t pretend that I had a planned career, it wasn’t like that at all. And it was the same here. I mean I was born after January so I stayed on, otherwise I would have become a radar petty officer or something. So here I was at college in a smallish group doing science, I’m trying to remember how many there were. There was one thing which was a little bit unusual in that there were a fair number of women. Yeah, because women of course were not called up and we had at least three women, if not four. One, two, three… I can think of three so there probably were more than three. No, I can think of another one, four. Oh no, I can think of another one, five. I think of Pat Trezona who later on turned up at Imperial College. And there were only, I would think that the class was about a dozen, it might have been fifteen but there certainly were quite a lot of women there. And of course in the rest of the, in the non-science bits there were very few men because they had to have something wrong with them medically or else they would be called up. So, it was an interesting group and we were essentially [1:25:30] sharing things with the Welsh college, where again there were the same restrictions on whether they could stay on at college, except for the religious part and there was a very strong Methodist presence there and anyone studying to be a priest was automatically exempt from military service. So there were a lot of men there but they all were supposed to be religious. Well, I didn’t notice much difference between their behaviour and the behaviour of the other people, I must say. They were all right, there was no problem being there, we never had any problems. We all got on terribly well with each other.

*What was student life actually like in Bangor?*

Well, there were some interesting differences. We were now in lodgings and it was different being in lodgings from being at school, obviously. In the first place we were paying so that was different. In the first digs I was in there were three of us: there was myself, Brian Bransden who I’ve mentioned, we shared a room, and there was another chap, Leon Jacobs. Brian, as I’ve said, was not doing the same physics course, Leon was. Leon was an extremely good looking young
man; blond, he looked very athletic though he didn’t do many sports as I recollect, but he was extremely good looking and that had its consequences. But he had come from a good school in Wembley. His parents had a fruit shop and he was quite well-off, not aggressively well-off, but quite well-off, his parents were reasonable. And he and I got on pretty well together and were friends for many years, but we didn’t share a bedroom, he had his own bedroom. There was another bedroom which was occupied by two soldiers who effectively as far as we could make out were running the railways. I hope they weren’t entirely responsible for running the railways because every evening they would be downing beer and whisky in quantities that would astonish you, because they would tell us how much they’d drunk, and seemed to be able to take it quite well. I mean they would have ten to a dozen pints of beer, plus whisky chasers, and seemed to be all right, though they were slightly the worse for wear when they came back. One of them, I remember the bigger one, I can’t remember their names. I can remember what they looked like. He was big and he had distinguished himself by winning, I think it was the George Medal, for bringing somebody out in London from a building that had been bombed when at least one of his legs, if not both, had been broken, and essentially he couldn’t walk, but he dragged this person out and saved their life before the building collapsed on them. He was very strong. I remember we decided we would play a joke on him because we were sure he was coming back drunk, which he generally was. So Brian and I and Leon fixed up a kind of latticework of his ties and braces across his bed before he came back. When he came back, I don’t know what he did, but I do know he just walked into our bedroom and took Brian’s bed with Brian in it and just raised it up, just like that with one hand, he raised the bed up until the bottom was level up with the ceiling and Brian collapsed at the bottom of the thing. He then walked out again, he didn’t do anything to me. I don’t know why he thought it was Brian – it was Brian, but it was also me and Leon had done this – and this was a man of enormous strength and, apart from this, as gentle as a lamb. The other chap was sharper, more intelligent I think, but we sort of settled down pretty well. I think they were there for the whole time that we were in Miss Jones’s, but that wasn’t terribly long because unfortunately Miss Jones did not keep the house that clean and we discovered that there were fleas and when we queried this with Orson Wood, our tutor, he said we can have dirt but not mobile dirt, which seemed to me to be quite descriptive, and rehoused us after the first term in a house that actually was nearer. Bangor is in two halves; there’s a very big hill, it’s almost a cliff. The college is called the College on the Hill, and the main building is certainly at the top of the hill, but the some of the more modern facilities are at the bottom and those are the science and engineering facilities so there can be quite a walk in going from the engineering or science up to the main halls and things. But people get used to it and it is quite useful, seeing the
college on the hill.  [1:32:20] I used to do cross-country running there but my cross-country running has a logical trait in it, that if I’m up with the leaders then that’s fine, but if I happen to fall behind I begin to question why I’m doing this activity, which means I start thinking and walking more slowly or running more slowly until I’m walking. And on one occasion I was doing this and was running, I mean this would only happen say, once in three or four, but once I was getting a little bit out of breath so I slowed up and then I realised I couldn’t see anybody, so I didn’t know where I was or where I was going. Now this was a bit strange because normally you can see the college because it’s on this hill. I couldn’t see the college, I thought I know I’m still in Bangor, how is it I can’t see the college? And I had no idea which way I should now continue to walk – I’d given up running. There was a lad, he probably was about six or seven, there and in those days you could actually talk to a child. So I said to him, I said, ‘Hi laddie, which way do I go to the college?’ And he looked at me and said, ‘No speak English’. And I thought God, I am out of civilisation here. And there were parts where English was not spoken, which I found very odd. And now you wouldn’t find it at all odd, there’s much more and if you go on to Anglesey you certainly find that people will speak Welsh all the time and there are some, I’m sure, particularly the young ones who will not speak English, but that came as a big shock to me and I realised I was in a foreign country. But not to worry, there are other things, we carried on doing our work and there were obviously inter-college matches and things in various sports and we were kept separate in that sense. The only thing which we did jointly was radio. This was compulsory. If you were deferred then you had to take radio lectures and this meant you had to sign in for them, I mean it was recorded back and if you hadn’t got the true record of attendances, then it was likely you would lose your deferment so it was important you attended. Attended is, it’s not really a description because you had attended when you had signed the list and it was not unknown for people to sit at the back – and this was in a lecture theatre at the bottom of the hill - you could attend the lecture and there was a window at the back and provided you could drop down, you could exit while the lecturer was not paying much attention. The lecturer, I have to say, was not a terribly good lecturer. I think he was called Mr Brayshaw and he would probably have been okay with a smaller audience, but because it was compulsory and because both colleges were together, the audience was probably seventy or eighty at least and he couldn’t observe everybody at the same time. I’m probably being a bit kind because it’s quite possible that he wouldn’t have been able to control them if there’d been only forty or fifty, but he certainly couldn’t control this number and it wasn’t unknown for people to sign the list and then nip out of the window at the back. I have to say that I may have done this myself once or twice. Not often, not often, because I was interested in radio and most people were too and wanted to – it was a
new subject and it was quite interesting, but a number of people just chose the signature thing as a challenge.

*What sort of things did they actually teach you on the radio part of this? Was it theory or practical or…*

Well, they couldn’t, I don’t remember us doing practicals in radio. We obviously did practicals in physics. They taught us how radio worked and I don’t remember anyone talking about radar, I have a feeling that radar was a bit more secret then. This was ’43 remember. I think we were taught about radio, I’ve got a book, Admiralty…

[end of Track 2]
I was interested in the compulsory sort of physics, the compulsory radio part of your course. How seriously did people treat it?

That’s not an easy question to answer because I don’t know that there is any general answer. As far as I was concerned it was an interesting subject but it was not a difficult subject. The level at which we were doing it was probably set so everyone could follow it, but what can you say about radio? As I recollect – it’s a pity I can’t find the book actually, maybe I’ll look for it and see if I can find it for next time, I know I’ve got it somewhere – you do a valve, you do radio waves, you do their transmission, you teach about oh, the relation between wavelength and the antennae, you teach about generation of radio waves, detection is relatively easy. It’s not a very deep subject, so I don’t know that it stretched people that much, it’s more factual than anything else. If I was being unkind, the book’s title, I mean it was ‘Admiralty Handbook for Wireless Operators’, so it was meant to be understood by people who were working a wireless set. Now, you would think that that is not quite at degree level. It doesn’t mean to say you couldn’t do a lecture at degree level, but I suspect Brayshaw never did. As I said, he was not a good lecturer and the fact that his discipline was not good enough to cope with such a large group of people meant that people did not treat the lecture as seriously as possibly it deserved. I can’t say what it had been like in the other years, but I suspect it wasn’t terribly well conceived. I doubt if it was something which the university had developed as a course, I think it was more a test and it could have been good preparation for somebody that was going to be called up to become a petty officer radar or something like that, as the two Jacks did. Of course, what happened to the people in the class in principle if they got through, if they got a good enough mark, they would not be called up anyway. I mean they would go on to do war work in doing science in a factory or in a government establishment. But I don’t know, does that answer your point?

Mm. Brings me on to another question though, where did you see this university course actually taking you?

Oh, didn’t know. Never thought for a minute. [sighs] Remember the procedure, what had happened. I’d been, I knew where I was going, I was going to the LCC. Mr Dalton said you shouldn’t do that, you should go to university. What’s university? Well, it’s the place where you
could learn more and where you would do quite well, why not. Okay, yeah. That was it. I don’t
know that anyone thought very much about it, you knew that it was a path to a better kind of job
than you could imagine if you stayed in the East End. What kind of job, I don’t think anyone
could even have explained it to me. You have to remember that we came from families where
nobody had ever been to university, so knowing what happened to you after university would
have been one degree further up. We didn’t know anybody who’d been to university, except of
course for the teachers. So I suppose at the back of our mind was the idea that maybe you’d
finish up teaching. In fact that was one of the things that I thought I would do. I didn’t know
anything about research.

What did your parents think about the fact you were going to university?

I don’t know that mum ever took it in. Dad was thrilled, I mean essentially it’s what he would
have wanted to do. I mean he would have liked still for me to decide I was going to be a doctor,
but he saw this as something marvellous.

What were the other subjects that were part of the university course?

You mean…

As well as radio, what other subjects made up the physics…

Oh, heat, light, sound, magnetism, electricity. More or less what you would have done at school
except it was never called sound, it was called acoustics and no doubt they had some fancy words
for it. There also certainly was quantum physics. I think one of the points about the thing is it
was a very intense course because you were only allowed two years. You had to accomplish what
then was done in three years in two years. So you had more lectures. I mean I can’t say that we
worked that hard, I seem to have spent quite a lot of time in the union, but there was no question,
they said, that you were cramming lectures in. And I can remember that the engineering students
used to have even more lectures than we did, we used to sneer at them because they were – we
said it’s bad - they had nine o’clock lectures. The idea that people had nine o’clock lectures was
amazing, we couldn’t imagine anybody having nine o’clock lectures, but then we would see the
engineering students queuing up for their nine o’clock lectures. This was only the Welsh
engineering students, ours were in Swansea. But we used to stand and jeer at them. I don’t know
how it is that we were there at nine o’clock anyway. I suppose we were on our way to the union to get coffee and stuff. But we certainly had a lot of lectures.

What do you think were your favourite parts of actually learning about physics, if any?

I don’t know that I differentiated really. I’m trying to think who did the different lectures. There’s no question that Orson Wood – oh, there was a difference. Okay. Orson Wood was a superb lecturer. He did light and heat, I can remember that. He always had words like ‘a very nice person’. And he had learnt early on that you could easily be distracted by what the students were up to, so he would address a beam that was up in the ceiling or near the ceiling at the back of the room, and his gaze would be fixed on this while he was giving his lecture. So it didn’t matter what the students were doing, he didn’t see them. Actually we did a test to see what he was seeing because before the lecture we actually put a notice on the beam that he was looking at. He didn’t seem to notice it, he just carried on doing his lecture. And there’s no question that my interest in physics was stimulated by his lectures.

What about his lectures in particular?

It was the way he explained the subject. I mean it was quite advanced but essentially he simplified it so that everybody could understand it, and it wasn’t just me that thought his lectures were very good, everybody came to his lectures. Now, GB Brown, whose name was Burniston Brown, G Burniston Brown, in fact there was a sort of rhyme about his name, he had a totally different way of lecturing which was essentially he wrote everything on the board – we had boards – in copperplate handwriting, if you can say it’s copperplate when it’s done with chalk – and he would write something on the board, including formulas, and then he would read them, basically. There was very little explanation apart from what he wrote down. So we rapidly decided that we didn’t all need to attend the lecture, that there were other things we could do during the day and as long as at least half the class went to the lecture, maybe a little bit more than half the class so he wouldn’t notice, the rest simply could have access to their notes and write them down, and there was no difference. Now, I’m not saying that he didn’t cover the subject. He had certain things that you remembered. He had a theory of dimensions that you did not need three dimensions, you could get everything from two dimensions, and he insisted that he was going to lecture on this. Quite why, I never knew, but anyway all this was there. You were never going to be examined on it because – not in your degree at any rate – in your terminal exam
you might be. But he would certainly do that. He did electrostatics and everything he wrote was
correct and he’d worked out his lectures but there was very little stimulus coming from his
lectures as opposed to Orson’s. [11:50] I will say that a nice example of Orson was when I was
doing some revision for the degree, which I have to confess was not that normal, I came across
one point in his lectures on heat which I did not fully understand. By then we were no longer in
college, he wasn’t there, so I dropped a note in his pigeonhole and said that I have this problem
and could you explain it to me. And he wrote to me at home and he explained this on a page very
clearly and then he wrote, ‘Since you will be taking the examination shortly, it could be that you
could benefit from some advice on the technique for answering papers, examination papers’. And
then he went on to a technique of doing it, and he said, ‘Read the paper carefully and then select
the first question that you know you can answer and answer that. Then choose a question which
you are not as certain about and answer that, and then go back and do the second question that
you know you can answer’. And then he had some more suggestions. And I thought, well, this is
not just helpful in the sense that the advice is good, it’s helpful in that he has taken the trouble to
write this for me, and I always thought that he was a very nice man.

Are there any other lecturers you remember in particular?

There were some lecturers obviously we saw later on when we came back to London. The other
one I can remember is Duncanson, WE Duncanson, he was a good lecturer. I can’t remember
anything, I can remember him. There were some other people that actually should be mentioned
and some interesting points about them. [14:25] There was a maths lecturer, a woman, called
Constance, always known as Connie, Rigby. There was a history lecturer called Bindoff, and
they took a great interest in the actual lives of the students in the sense of, I don’t mean their
morals, I mean their morale, and their situation. And they collared me in the first term, which
was interesting because they hardly knew me, but they did collar me and said there was an
organisation called CASH, at which I pricked my ears up. I said, ‘Well what is it?’ They said,
‘It’s the Committee for the Alleviation of Student Hardship’. I said, ‘Oh’ I said, ‘What does it
do?’ They said, ‘Well, we have some funds and basically we want to make sure that nobody at
college here in Bangor’ – though it was in general, there were probably other bits – ‘goes short of
money. And so there is a system, there are notices up and if anybody is in financial hardship they
can apply to us’. I said, ‘Yeah, well what’s that got to do with me?’ They said, ‘We’d like you to
come on the committee’. I said, ‘You don’t know me’. And they said, ‘Oh we know about you’.
And I thought, what the hell? So I joined and at the end of the year I was made chairman. Again,
I never quite knew why or what, obviously I did it and it worked very well. And then we were coming back to London and they said we want to develop CASH, to broaden CASH and turn it into a health service. I said, ‘What do you mean?’ They said, ‘We want to start a student health service at the college, so every student gets medical advice free and we are going to do that together with UCH, which is just across the road from this’. So when we came back to London we started the Student Health Service and I was chairman of it, again not knowing quite why and they said no, we must have a student running it and you will be the student. So I said fine, and that developed of course into a bit of the National Health Service and still exists at UCL. So UCL I think was the first college to actually develop medical advice for all students free.

Do you think you gained anything out of those experiences?

Oh absolutely, yeah, sure. Yeah, I learned sort of of the problems people had, the solutions you could find for them and also the need to keep things confidential. Not everybody wanted things known there, so you learnt things about people which surprised you and which you knew you couldn’t tell anybody about. I mean not everybody wanted people to know they were short of money or their parents hadn’t sent them money that they’d promised them or things like that. And similarly, the fact that somebody needed medical advice was something they wouldn’t necessarily want you to know. Obviously you didn’t know what it was, I mean I think maybe Connie did know, but Connie became quite a well-known figure in UCL and Bindoff of course was very prominent in those things and as I say, he was history. I don’t know whether that gave you a broader view of life. Well, Connie was maths and that certainly doesn’t. But that’s an interesting side thing of the interactions that happened and I suspect it happened more because you were a closed community in Bangor. [19:00] I mean it was only part of the college.

I think I have really just one final question I’d like to ask you today before calling it a day and I was just wondering, apart from running, what else do you do for fun at university?

What else did I do?

Mm. For fun.

For fun? Oh, I mentioned cross-country running but I also did normal athletics as well. I decided I would run shorter distances where I didn’t have to think that much and that continued, in fact I
ran at NPL as well later on, much shorter distances. I did cricket, I played for the college at cricket, not that that was that remarkable as a testimony to my ability because I don’t think we had probably many more than eleven people who wanted to play, but we did play at college. But I took a great interest in dramatics, in the DramSoc. We’ll get later on to my personal life, but I met Betty. Betty did French at UCL and we got together and stayed together for some, well nearly forty, well it must have been over forty years by the time, but she… We were billeted – billeted – we had lodgings in Bangor but the French, who were mostly women, I think there were two men in them, they were in Llanfairfechan, which is just along the coast, so they came in by [bus]… So we didn’t see each other immediately that often, but in any case we both were working quite hard. But essentially we both took an interest in dramatics, so there was a very active DramSoc which put on performances and particularly the two that we did were Pygmalion, where I was Doolittle, and Betty was something, Eynsford-Hill, the woman. And then we did, They Came to a City where I was Cudworth. I forget what Betty was in that, she certainly was in it. It was run by a man called Christopher Beedell, I don’t know what happened to Christopher, I think he was doing arts in some way, so he must have had deferment in some way. But Keith Puttick was also in it and Keith later on turned up at Surrey University as a professor. But I think he did a general degree, he must have done quite well. But that was quite time consuming and we performed, we didn’t just perform at the college, we actually performed at RAF bases around the area, went round and did that. So that took up time. Oh, I think there were other societies that we belonged to, I can’t remember them all, but the days seemed pretty full.
It’s a question of what more we need to say about life in Bangor. I don’t think I mentioned that we obviously were sharing some facilities with the Welsh college and there was clearly going to be a problem with practicals, and the staff had actually rented or bought a cycle shop in Bangor High Street, which was where we did our practicals. We took that pretty well in our stride, it was a bit unusual I suppose, and occasionally we did have somebody coming in sort of asking if they could buy batteries there and we had to explain it was no longer a cycle shop. The lectures were not terribly frequent, thinking about it, as I have been doing obviously since we started this exercise, and I suspect that there is more lecturing now than there used to be. I think that we were told we had to rely quite a lot on private study, that the lectures would give us a framework in which we could fit things and then of course we could ask questions, but we would be expected to do a lot of reading. Now, of course I don’t know that everybody did that. But hanging over us all was the possibility that if we didn’t pass even the terminal examinations we would be called up. I’ve said already that not everybody was allowed deferment, it was only those that were born in the second half of the year and we knew that our marks were being surveyed in order to ensure that we were being kept up to the mark, and that was of course one point about the radio lectures. So there was always some pressure on us to work reasonably hard, but that didn’t mean to say that we didn’t have quite an active social life. Clearly it was slightly unbalanced because there were, well, the gender ratio was slightly more than one would get these days, even though there’s a preponderance of women, I mean almost all the arts faculties, there were one or two men there but they were people who were really there because they either were very young or were invalids in some way. I don’t mean invalids, I mean that there was some medical reason why they couldn’t be called up and I suspect that that got more difficult even later on when there was more or less a shortage of manpower. And the exception of course was the theology and divinity students at the Welsh college. We didn’t have that in UCL, but they were deferred too and as a result most of the Welshmen who were around were doing religious studies. You couldn’t always tell that from their behaviour, mind you, but we knew that they were and they were a very nice crowd actually. I mean all of them were very easy to get on with. There were surprisingly few incidents, when you hear now of fracas, and of course when we got back to London – we’ll get to that – we did have arguments with King’s College, but I can’t remember much happening in Bangor of that kind. That doesn’t mean to say there wasn’t a fair amount of drinking. I haven’t sort of spoken of rationing at all and there was quite severe food rationing. I mentioned this to Anne, my partner, and said that one of the things that certainly hit me was the
shortage of sweets, because we got only twelve ounces of sweets a month. And her comment was, that’s almost three-quarters of a pound. I said, well it’s a bar and a half of chocolate a week. I don’t know whether my mind was on chocolates because my father sold them, as I have said, but thinking about it, twelve ounces of sweets seems to me to be very little, even now, very little and then I’m sure that I thought that I was suffering in only having that. We did turn over our ration books to our lodging lady, the landlady, and she provided breakfast and dinner, I mean eggs and bacon were obviously rationed so she would do that, and meat was rationed, as was butter, cheese, margarine and things. But no bread, bread was not rationed until after the war. And that meant we had to find lunch for ourselves and you could get lunch in restaurants, you couldn’t always get what you wanted and there were British Restaurants, there was a British Restaurant – it was called British with a big ‘B’ and a big ‘R’ – where you could go and get in and there lunch cost four old p, which is about two of our p now. So even with inflation you can’t imagine that it was remarkable, and it wasn’t, but it was meant to keep everybody going so they could go and have a meal in the British Restaurant, and there were other restaurants. I don’t remember going hungry so it can’t have been that bad. It was a kind of artificial life there because we were away from home, we knew we weren’t in a complete college, and there was some feeling that you almost were in a foreign country with quite a lot of Welsh being spoken around you. When you wandered in the main street, I mean the language that a lot of people spoke was Welsh. We did learn a little but I can’t pretend that many of us actually put in any effort to learn Welsh.

[07:00]

_Talked a little bit about the lectures you had at Bangor and the lecturers, I was just wondering what were the practical classes like in the cycle shop?_

Well, I can remember, I – we had a partner, I had, my partner was Leon, Leon Jacobs who I’ve mentioned before. Brian, who was the third person in our digs, he wasn’t with us so he was doing this general course so his practical was done separately. But Leon and I did things. It was fairly standard. I can remember that we had to do a Kater’s pendulum experiment. Can’t really remember what Kater’s pendulum was, but I think what you did is you took a metre rule and you suspended it at one point and measured how long it took to act as a pendulum and then you turned it over from top to bottom and did another measurement and from the two measurements you could do an averaging which meant it was independent of something or other, which could have been the uniformity or the density of the pendulum. And I remember that I worked out a way of measuring the time this pendulum swung because clearly it was a standard pendulum and
the time gave you the acceleration due to gravity in Bangor. And I worked out a method of measuring this by coincidences with lights coming through slits and things, which seemed very impressive and we thought we were measuring the time of this pendulum extremely accurately. When we came to actually work it out, I think we proved that the acceleration due to gravity at Bangor was about fifteen feet per second, per second lower than it ought to have been. And Leon and I decided that the lecturer – I forget who looked after us, I think it may have been Duncanson – would not have been impressed with the fact that we had an extremely accurate method of measurement but it led to a very inaccurate answer. So we trimmed our results so that we got the acceleration due to gravity that Kaye and Laby reckoned it was in Bangor, and everyone seemed happy. Never really did understand why it didn’t give us the right result because I was pretty proud of that method of measuring time, but not to worry. Other than that I imagine they were fairly standard experiments. It was quite a large cycle shop and as I’ve said, it was not a large class, I think it was about twenty people in all. So if you each had a partner that would only be ten sites so it would have been relatively easy to do. Now it would be quite impossible of course with the numbers they have.

*Having problems actually sort of reconciling the image of what I think of as a laboratory with a cycle shop. What does it look like inside?*

Well, it won’t help us here. I can actually show you a picture of it if you want to see it and turn the thing off.

*I’ll be interested to see that in a moment, but your memory of what it looks like I think would…*

Well, it was more or less as I remember it. There were tables around, clearly a shop has an open area and a counter and things and I think in this open area there were a number of tables at which people could do their experiments and the counter and behind it was used for stocking the scientific equipment that we were using. I seem to remember that there was actually a step, the shop was in two halves, but that may be not so. I have a feeling it was. But I don’t think it affected what we were doing and clearly we did what you normally do, is do your experiments and then write them up. I’ve said there weren’t that many lectures but there were sufficient to keep us busy. [11:35] But there was also an active social life with many societies, things that people joined, and I’ve mentioned the dramatic society, but there were others. And there was a maths and physical society. I can’t remember many of the lectures that came, later on in the
second year I think I was secretary of it and had to actually arrange lectures from people and it certainly was possible to get visiting speakers coming and talking about specific subjects. But I was saying, the atmosphere was a bit strange because though there were clearly signs of war with the rationing, and I mentioned the two soldiers who shared our lodgings who were looking after the railway, the bombing was completely over as far as we were concerned. I imagine that was linked with progress in the war on the Continent where the Germans were busy in Russia, but essentially, you see, at the time of the Blitz it has to be remembered that Ireland was neutral, so that meant it was alight at night. So if anybody wanted to get to Liverpool or to Manchester or that area, it was relatively simple to fly up the Irish Sea and when they got to Dublin or a little bit beyond they would turn left… turn right, and follow the north Wales coast and they’d relatively easily get to Liverpool. And then of course if they couldn’t drop all their bombs on Liverpool or were left with some, they would come back and they might well drop some on north Wales, which they did and I think there were at least two bombs, maybe more, landed in Bangor. But that ended in ‘42 as far as I remember. There weren’t any more raids then on Liverpool and even London was much quieter. So there wasn’t that kind of feeling that you were at war. So all in all it was a fairly strange atmosphere. I suppose you could argue it was one where there was every opportunity to study quite hard. I don’t somehow feel that that was the atmosphere in which people were going, I think that they studied reasonably hard, but there was no overworking or towels round heads or working until the small hours, certainly not. And as I’ve said, there was rationing, but there was no rationing of wine and beer. Beer mostly, as far as I remember, I don’t think that many of the students were into wine, that came later.

[15:00]

What was student funding like from the point of view of someone who’s spending it?

Student funding?

Mm. How well off did you feel, or not?

I was lucky. I’ve only become conscious of thinking of fees more recently, but I do remember that I took the London Colleges Scholarship, I suppose it was. It certainly was a scholarship of King’s College and UCL combined. I think I mentioned actually that I had gone up to Cambridge and tried a scholarship there. I’ve certainly mentioned that I didn’t do chemistry at school for very inadequate reasons, but it meant I couldn’t take a natural sciences scholarship, so I had to
take a maths scholarship with physics as a subsidiary and the maths was a ridiculous level, I hadn’t done any of it. In fact most of the people up in Cambridge, and I don’t understand how they did this, they must have been young, but they’d all got their A levels and had done an extra term, I hadn’t of course and I certainly couldn’t cope with the maths. I did pass in the physics, but then the question would have arisen as to how I could have afforded to be in Cambridge and it was generally thought that I wouldn’t be able to afford it. But London was a different matter. We took the UCL/King’s College exams and both, well a number of us passed that and I certainly passed it so it meant that the fees would be paid and then I learnt that if I got a state scholarship that would give me £100 a year. Now, they weren’t easy. I think they were perhaps over a hundred for the whole country, but I did get one. In fact the school got three, which was extraordinary. And that meant that I was reasonably well off compared with other people. I think I also had a small scholarship of twelve pounds from the school. So I had enough money so that I was able to live in Bangor and give my mother some money when I came back to London for the vacs. Other students were not as well off and I have mentioned CASH and though obviously, though I was on the committee, I was not given individual situations. All the applications were anonymous – Connie and Stanley Bindoff knew of course who they were - but there were a fair number of applications. I imagine the college must have provided the money, I can’t imagine anyone else providing the money. But certainly there were a fair number of students who could not have managed, clearly incomes were a lot lower then and a lot of the people would not have been able to pursue their professional jobs during the war, so a number of the students would have been more worse off than normal. So, not that there was that much you could have spent money on anyway. There weren’t luxury goods around. It wasn’t a major feature of life, people got by.

*What do you spend your money on as a student in the 1940s?*

Well, eating and drinking. I imagine that, well I suppose the social events, there would have been a subscription to the clubs but that would only have been once a year. [19:20] There were regular dances. In fact we had some very good bands came. And those were joint with the Welsh college. We had many things separate from the Welsh college, our clubs were largely separate, but the Saturday night dances I can still remember we had the RAF band, the Squadronaires, coming on occasion and they had some musicians who later became quite famous like George Chisholm, Harry Lewis I think was there who later married Vera Lynn, and Ronnie Aldrich. So there was good entertainment that way. I can’t remember Bangor having a theatre and I can’t
imagine we could have gone along to Llandudno which possibly did have. But I don’t think we did that, that was not normal.

[20:20]

*When did you actually return to London?*

The original plan was that we were going to go back in the summer of ’44. Just a historical note – ’43 was the year when things began to change and it became clear that we were going to win the war. I don’t think anybody ever thought we weren’t, but that I think was really based on arrogance rather than anything else, but by ’43 and certainly early ’44 we were already occupying North Africa, landing in Sicily, beginning to progress up Italy itself. The Stalingrad had come much earlier, the end of ’42, ’43 and it was – and the Americans were coming over and people were talking about landing, so it wasn’t that surprising that by the beginning of ’44 people were beginning to think that we would go back to London and we were planning that way. The reason why we didn’t was not because of the V-1 landing in London, I mean that was a complication but it wasn’t thought to be serious enough to stop us going. What stopped us basically was the shortage of accommodation in the college. The college had been bombed quite hard, first of all in I think, suppose it was ’40 and then again in ’41 and quite a lot of facilities including the library were destroyed and it was thought that not everybody could come back. I’m not sure who did come back, but essentially nobody who was in Bangor was going to come back then, we were going to come back at Christmas ’44 instead of September. But we did come and help, there was a lot of preparation necessary. I don’t mean clearing up rubble and things, I mean getting the quarters ready for the staff and the lecture rooms ready for the students and as I have told you, I was supposed to be helping JBS Haldane put up his shelves and we had a situation where I was holding one half of a quite large Dexion aluminium angle girder for him to put some shelves on and he was holding the other half and I put bolts in to secure mine to the vertical frame and he was about to put his bolt in when he dropped it, and then unthinkingly he bent down to pick it up and let go of the girder. And the next thing I discovered, I had this famous biometrist sprawled at my feet with blood coming from a cut on his forehead and I had visions of being remembered in college as the person who brained Haldane. I got help and fortunately he recovered his consciousness. He was knocked out by it, it was a big girder that just had hit him on a sharp edge. But he recovered and rather sheepishly admitted that he had acted foolishly and unthinkingly in bending down and letting go of the girder. I don’t remember helping much after that, I think I’d had enough. So we all went back to Bangor and there was a change now, because
this had all happened very late and the Welsh college, UCNW, University College of North Wales, had already made the assumption that they were going to be on their own and some of the accommodation for the students in Bangor had already gone. So physics was going to be in Llanfairfechan, which is a small village about eight miles along the coast to the east. That was not bad for some of us because the French students – and I’ve said they were mostly female – and I think quite a lot of the English and history ones had been in Llanfairfechan for the previous year, so Betty, my girlfriend, I then was in Llanfairfechan so she and I were pretty happy that it was going to be much easier for us to get together. The other thing that was interesting was that we were now going to be self-catering. Whereas previously in Bangor we had just passed ration books across to the landlady and she’d taken care of it all, now we handled our food, though I seem to recollect that the landlady did the cooking, that she did the cooking with meat and stuff that we actually bought. So we had to do our own shopping, which was interesting, and we got to know the shopkeepers and discussed meat cuts and things, which was a little bit strange. And quite a lot of the discussions had to involve some Welsh too, so that was useful. A slightly different life, of course we had to travel into college more, but that didn’t take long. A bus ride, about half an hour I think it took. So it was okay and we had our own social events there, more social events. I seem to remember that there was a village hall which we could get together in quite often, so it was more communal there. And this was only for one term. We were going to go back, so we returned in Christmas and by then there were rockets but no V-1s. We also now had to think more solidly about what we were going to do afterwards. The arrangements were that if we didn’t pass the degree, and I think that meant we had to get at least a lower second, I don’t think a third would have been adequate, if we didn’t get that we would be called up, basically, and join the forces and do something that exploited what we had learned, which might have meant that we became radar operators or radio operators or something like that. On the other hand, if we got a reasonable degree we then would be given the choice of going to a government research establishment of which there were quite a few – we’ve talked a bit about this and there was TRE doing radar, there was Haslemere doing radio and signals and there were establishments for the other forces as well. We could – that was one choice – the other was to go and work in the defence industry, and much of industry was defence industry then, making equipment for the forces, and we could choose that. And to make that choice, which was done sometime in the spring term, I have a feeling that it was going to be about March or April, we would be interviewed and that panel would be headed by either CP Snow or Harry Hoff. Now these are names which became more well-known later on. Harry Hoff was, wrote – both of them were authors, both of them were scientists, both physicists. I did not appreciate that, they’d both
qualified at Cambridge. And I knew that they were involved with government work and recruitment of scientists in some way. I think there even had been some return of scientists from America to the UK during the war. But anyway, they were certainly responsible for interviewing the graduates, well the undergraduates before they graduated. William Trevor I think was the name Harry Hoff wrote under. It was William something. When I turned up I was a little bit surprised to discover that they were both there, it wasn’t one or the other, they were both there. I was surprised, they were surprised with what I had to say because by then I had been contacted by Edward Andrade who was the Quain Professor at UCL, though he was not in residence, he was an occasional visitor. He had been professor and head of physics since 1928 or something like that, but during the war he’d been working for the Ministry of Supply. Of course there wasn’t anything for him to do in London anyway since physics was evacuated, but he’d never shown up in Bangor that I knew, so he was a stranger to me. He was a metallurgist and he had quite a reputation as being a difficult man. He had clearly discovered that I was top in the class – it wasn’t a big class I emphasise – and came to see me and asked if I would like to stay on and do a PhD with him. It was supposed to be on the viscosity of liquid caesium and he gave me some papers to read on the work he’d had done or had done himself on viscosity of other liquid metals. It didn’t seem to me to be a very difficult project, it involved having the metal in a hollow sphere, which you suspended and then you twisted and it rotated and as it oscillated it would slow down and there was a formula saying how that detriment in its rotation, amplitude and velocity would depend on the viscosity. So I agreed I would do that and put this to Hoff and Snow. They did not take too kindly to this. They sent me out of the room and said they wanted to have private discussions. They may well have wanted to ring up Andrade. When I came back in they said you will not be given the choice. I think they could have added, because of your cheek. Because I’d said that it seems reasonable that this should be possible because the war is ending. They did not like the idea of a twenty year old predicting the end of the war. I don’t know why, but they certainly didn’t give me the choice. They said you will go to Haslemere and work in the radio department on antennas. And I think they actually did me a favour because I don’t know what would have happened if I finished up doing the viscosity of liquid caesium, I probably would have gone mad. But other people did do it, a person I came to know quite well in fact, Roland Dobbs later did that PhD and it seemed to do him no harm because he finished up as quite a leading professor at a university, so who knows. But I was going to go there. [33:40] Meanwhile I had to live in London and sort of try and pass my exam, which was okay, I had very few problems with that. And I was living at home. Again, I’m not very certain what the background of most of the students at UCL was, but I assume that a fair number actually were
from London, and so the return to London could have meant that they were living at home. I know for instance that Leon lived in Wembley, though Brian Bransden was from the north. I think he was from the north. So there were a fair number. Betty, on the other hand, lived in Coventry, but although accommodation was pretty scarce in London, a lot of it clearly had been destroyed, the college had bought three houses in Gower Street which they turned into lodging rooms for women students. So they were very near the college, obviously. I was at home, by then we were living in Streatham so that wasn’t difficult. There was one dramatic event that happened on Palm Sunday in 1945 where I had been out with Betty and had taken her back to the college rooms, as had a number of other students taking their girlfriends back to the college rooms, and we had to leave college rooms at ten o’clock, things were pretty strict in how much consanguinity you were allowed with the female students. And we left and walked along the road, I imagine we were going towards Goodge Street Station in Tottenham Court Road. We’d almost got to the end of Torrington Place when a rocket fell on Whitefield’s Tabernacle which was at the other end of Torrington Place, and destroyed, I mean the rocket destroyed the Tabernacle and a lot of the houses and road around. I suppose you would say it was about 200 yards away, but it was too near for comfort and if we’d been round the corner, we certainly would have been affected by the blast. Quite what it would have done, I don’t know. But it was pretty dramatic, have a rocket that near you. Not something I would advise for anyone. But we weren’t round the corner, we were about twenty yards or so from the corner, so we did peep round to see what the hell was going on, then we decided to retreat and we thought we’d better go back to the college rooms and just explain to our own young ladies – I think there were about half a dozen of us – that we were all right. So we went back and there was clearly quite excitement already and they were opening doors and we were treated to the sight of quite a large number of young ladies in their nightgowns, which we hadn’t seen before of course, being very nice young people. And that was the talk of the college of course for quite some time afterwards. Meanwhile, things progressed quite reasonably. There was VE Day, which meant there were lots of processions and we took Phineas – Phineas was our wooden mascot which was quite big, he was a life-size mascot, he had a kilt, he was Scottish for some reason. I don’t know his origin but he was the college mascot and he was brought out on occasion, and was stolen on occasion too by King’s College, but that’s a different story. And we took him to Trafalgar Square and I still remember seeing in the News Chronicle which was a paper that existed at that time, you could see Phineas in Trafalgar Square and you could even see a lock of Betty’s hair near him. I was there but I don’t think you could see me. I was in the crowd somewhere. But that was big celebration, VE
Day. And lots of the students stayed overnight in the college so as to take full advantage of all of the celebrations that were going on.

_How did it actually feel at the end of the war? For you?_

We knew it wasn’t the end of the war of course, because it was VE, Victory in Europe, and it was, it was clear there would be changes. I don’t know that it meant that we were going to actually have an easier life in the sense of rationing, because in fact bread rationing was brought in. Rationing didn’t stop for quite some time and that wasn’t just rationing of food, it was rationing of clothes and furniture, that you couldn’t just go out and buy things. If you were getting married you got an allotment of coupons for furniture, but clothes were rationed as well. So life didn’t become much easier, but of course it got a hell of a lot less dangerous. That rocket that landed on Whitefield’s Tabernacle was actually the last rocket to land in the UK. Curiously enough, there are only three places where rockets fell. There were about 1400 rockets landed on England, of which fifty-odd fell in Norwich. No, don’t ask me. And one fell in Ipswich. That makes a bit more sense because maybe they were aiming for a port and Ipswich is nearer the port. You can’t imagine quite how you could go wrong by targeting Norwich, but in fact fifty rockets fell in Norwich. The rest all fell in London, in different parts of London. But that finished, as I say, in April and after that it was just a question of the armies occupying most of Germany. But we still had to reckon with Japan and we took our examinations. I did quite well, I got a first, and that was all right, and I got the Rosa Morison Memorial Medal, which was for science students that had come top at UCL, which was encouraging. And then I got a letter from my Lords Commissioners of the Admiralty, which was nice, and this was in I suppose August, it might have been early September. I was due to go to Haslemere, remember, and work on antennas. And the letter said, from my Lords Commissioners of the Admiralty, with an Admiralty anchor at the top and everything, very official. ‘Dear Sir, since you agreed to join us the Japanese have surrendered.’ I thought that was very sensible of them. Mind you, it then went on to say, ‘As a result, you will not need to go to Haslemere, instead we would like you to report to Fanum House in Trafalgar Square and work at Admiralty Headquarters’. Now that was quite convenient, I mean I was pretty happy with this. Remember, Betty was in London and she now was going to do her teacher’s training, I think, I think she was going to do teacher’s training. I think she’d also got her degree. No, maybe she had to do another year for her degree. She did a course for art students, and female art students they weren’t called up, so I think she could do another year in London. But it meant I would be local, instead of being in Haslemere, which was fine. Fanum
House had been the headquarters of the Automobile Association, but of course during the war and just afterwards the government commandeered various buildings and the Admiralty had part of their headquarters there and in particular they had the infrared group and this was where I really started my professional career.

[43:20]

Before we go any further, I had just one or two minor clarification questions…

Yeah well, this is definitely a break point. I’m now working.

What was Betty like when you first knew her?

What was she like? Lovely. She was very popular, I could never quite understand why she wanted to be with me. An interesting point which – I have mentioned Leon. Leon Jacobs was my best friend at college, because though I was close to Brian, Brian wasn’t doing the same course and Leon was and I’ve said that we were partners in practical and things. And we did most things together. But we were different. Leon was a tall blond who was extraordinarily good looking. I wasn’t, right. I was small and dark, right. Leon as a result was extremely popular with the fair sex, the other gender, but what they didn’t know and what I knew was that Leon was extremely religious. Now this combination is not good, to be very good looking, very tall, breathing masculinity and really being so religious that he didn’t want a lot to do with people who weren’t religious. I mean he put up with me, but that was all right, but he certainly wouldn’t have dreamed for a moment of misbehaviour of any kind. But that wasn’t easy to explain to people and as a result he was not terribly sociable, because he was aware of the potential of misunderstanding. As a result, I became more popular because people would want to get to know me in the hope of getting to know Leon, which was frustrating to have people who wanted to get to know me, not because of me, but because of who I knew. So the whole thing was terribly artificial and to explain to them no, there’s no point in my giving you an introduction to Leon, you won’t get anywhere. They just didn’t believe me. They thought I was sort of playing hard to get for him. But anyway, he was a very nice person, but he wasn’t terribly good at his work because he suffered from severe headaches as well and in the end he didn’t get a degree, he had to go out during the degree examination. [46:20] I don’t know where we were, what was I explaining to you?
I was asking you about Betty.

Sorry?

I was asking you about Betty.

Oh, Betty. Well I could never understand. I was saying, because of this I was quite popular with the women in a slightly different way. But Betty was very good looking. She was doing French and was clearly making a mark sociably and she and I, we got together I think at the end of the first term and we met at a dance and she liked dancing as I did, and we gradually got closer and it became pretty clear to everybody, including us, after a few months that we were going to be a couple. And indeed we were and we married in ’47. I don’t know that it entirely met with the approval of her parents. They were shopkeepers in Coventry and Betty was the youngest of four girls. The others had all done ordinary jobs and like me, she was the first one in her family to go to university. But her parents had wanted her to become a teacher and they were pretty certain that if she got married early she would become a housewife and not be a teacher. That didn’t happen of course, but it was difficult to persuade them that I wasn’t a diversion who was going to really stop Betty from fulfilling her ambitions. And indeed they were very concerned at the money they had spent in putting Betty through college, because she hadn’t won, she had got a scholarship but she hadn’t got a complete scholarship and her parents had supported her. And indeed, I said more or less that we’d better pay them back, and we will pay them back, but they took a token payment but by then they were happy that I wasn’t going to condemn Betty to a life in the home of a kind, that I also wanted her to do things, so they said no, we don’t need the money, you can have that. Money was in short supply. [49:25] When I joined the Admiralty they gave me the grade of Temporary Experimental Assistant grade three and as I used to point out to people in talking about my career, there was no grade four. You could not get any lower than grade three. There was a man called Van Grutten, I still remember it, who was what we would call the HR person and then he was responsible for personnel and I, when I was interviewed by him and he told me what was going to happen, I pointed out to him that I knew that in other government departments, graduates, particularly first class graduates, were being taken on as junior scientific officers, which was a better sounding title and was also, it carried more status. And he said well, I’m afraid that that isn’t possible here, but if you come in as a TEA3, I can get you promoted in three months to a JSO. So it’s only a question of three months’ waiting. I said oh, in that case that’s okay. And he said, and what I will do is I will give you a
salary rise straightaway. Instead of it being £225 a year, you will get £250 a year, I think. So I was pleased. What I didn’t know, now this was, remember, September I suppose when I had this interview after I had the letter, I didn’t know he was leaving in two months’ time. He knew he was leaving in two months’ time. That also figured in the lectures I used to give in the Civil Service afterwards. I said, never believe in the promises of senior personnel, they have a habit of leaving before they need to actually fulfil their promises. And everyone wrote this down religiously and I said, believe me, I know. And I did know because this had happened. So I joined as a TEA3 and, at 250, and with [52:00] my first pay cheque I bought an engagement ring for Betty, which was a promise I had fulfilled her… it was only twelve quid, in Bravington’s. We bought it in Bravington’s at Piccadilly Circus. I don’t think it’s, well I’m sure it’s not there any more. So that was Betty and that, Betty meanwhile obviously was still studying and though I was working in Fanum House – and we’ll come to that as to what I was doing – I was still able to go to college and could attend lectures. I’ll come in a minute as to how I do this, but it was a fact that lectures were going on and the first time I went to lectures by Dr Chalklin on X-ray crystallography. Nobody seemed to be bothered, so I used to turn up and go to the lectures and when there was an interesting lecture I would go. And it was very useful. So, life proceeded and we knew we were going to get married at some stage when we could really afford it and find somewhere to live, and when Betty had finished her training. My job, you will want to know about.

*I think we should look at the Admiralty as a separate chapter. But I have one other quick question before we move on any further. I was just wondering, what were CP Snow and Hoff like to meet in person?*

Can you say what people are like when you have an interview? I would say they started off being friendly and they finished up being frosty. I’ve never really tried to put myself in their position. I mean they were used to a rota of people coming through, they knew what degrees they were likely to get and they would discuss with them where they would fit in best in different government establishments or different industries, and I suppose they were in a sense looking forward to talking to me, for I was obviously the top graduate in science there. I mean not just in physics, but in all the things there I had clearly got good recommendations from people, I knew that from what people had said. And then suddenly I was disappearing from their remit by staying on at college and they thought this was cheeky I suppose, so they didn’t warm to me. They didn’t know this, they were not given previous notice, I mean they sat me down and were
going to have a nice chat about physics I suppose and asked what I had in mind and suddenly out came this bombshell, which they weren’t ready for, and it all went wrong. They seemed slightly bad tempered, I must say, but I can understand that better now than I did then. I was very naïve and I have very little doubt I did not put it in a diplomatic way. Of course if Andrade had been a more sensible and less aggressive person he would have had a word with them before the interview, I mean there was no reason why he shouldn’t, and sounded them out on this. It shouldn’t have been left to me to put it to them, it should have been him who did it, but he clearly hadn’t. I don’t know whether they sent me out of the room just to moan together about this cheeky chap or whether they actually wanted to contact Andrade just to see what the hell was going on. But I can only say that I got the sharp end of it. Not that it mattered in the long run.

[end of Track 4]
What was Fanum House actually like? Can you describe it to me please?

It’s still there of course. It’s on the, I suppose it’s the west side of Leicester Square. It had a pretty impressive frontage with steps, marble steps going up to it. It’s six or seven floors and occupies I suppose about one quarter of the side of Leicester Square. It housed quite a few of the science departments there. It housed what later became the Royal Naval Scientific Service, though it wasn’t then called that, though it was called it shortly afterwards. It had the library at the top floor and our group occupied two offices I suppose, on probably the second floor. It handled coordination of the infrared programme of the Admiralty rather than anyone else, though the Admiralty was doing most of the infrared work. Well, I can give you some of the background, though clearly I hadn’t been involved in this, though it does set the background. That essentially infrared was used by all of the nations but they had different strategies, but essentially – when I say all the nations, I have no knowledge of what the Russians did then, I knew something about what they did later as will become apparent. The Germans were alert to the possibilities of infrared sensors and infrared images early on, as were the Americans, but both of them tended to be sophisticated in what they were doing. The British view was much more to be simple, as a result of which the British made much more use of infrared during the war. The key to what the British did was the tube that was called an image converter tube, which essentially converted infrared radiation into something you could see. Now, this is near infrared radiation, just outside the visible spectrum, just slightly longer wavelength than red, and you could have a photocathode made of caesium silver oxide, which has the right properties, the right work function for acting as a cathode in a, electron optical tube. Again, the Germans and the Americans both had image converters which had electro-optic systems in them for making the image. It is obvious that you put an image on the photocathode that’s on the inner surface of a vacuum tube. The electrons are emitted from this with a one-to-one correspondence with the infrared picture you’re putting on and now you accelerate the electrons towards a phosphor screen which then gives out light that you can observe through an objective, an eyepiece. The difference is that both the Americans and the Germans wanted to have a good electro-optic system so they could get a very high quality image. The British decided that the simplest thing to do was actually to have the photocathode within a few millimetres of the phosphor screen and just accelerate the electrons across in a one-to-one pattern without any electro-optics, without any electro-optics at all. You just had a few kilovolts, well you actually could manage with even less
than that to get some of the pictures. So what you had was a, illuminator, a searchlight beam that had an infrared filter in front of it that illuminated a scene and then you had a simple lens system that focussed a screen, effectively a simple telescope, that you produced that then focussed the infrared radiation coming off from the scene on to your photocathode and then this would be immediately attracted by a few kilovolts to your anode, which was your phosphor, which would shine up. [06:00] Now the first thing was, how the hell do you get this thing made, and this was largely done at EMI, Electron Musical Industries, where there were some pretty good vacuum tube engineers headed by Dr McGee, who was a Fellow of the Royal Society and various other things and was the scientific director. And they, the programme to make this tube was under the code name, RG and they were called RG tubes, RG standing for radiograms, because that was His Master’s Voice of course and all that kind of thing going on. And naturally the thing was secret. The way in which you make that photocathode is very sophisticated, because you have to evaporate caesium on to the screen and then you have to oxidise it and there has to be a thin silver layer. And that is quite sophisticated in the way you do it. You’ve got to evaporate it before you seal it up and there’s a clear problem in how do you get two surfaces close together when you want to evaporate one on the other. And this was done with a very clever arrangement. Though these things were actually about, in the final tube, a couple of millimetres apart, in fact the tube itself was a cylinder of glass with two surfaces that it was, I suppose about two and a half inches in diameter, and the tube itself has a separation of about, about five centimetres, about two inches, maybe a little bit more. And the screen is held at right angles to the photocathode first of all and then the photocathode is prepared by evaporation of caesium and silver and then oxidising, and then the screen is unhinged from where it is at right angles by a magnetic catch and a magnet is used to lift the catch and the screen then falls down and another catch holds it in place. Which then means you’ve got your two screens, they are about two inches away from one side, which is where your eyepiece is put. So the whole thing is extremely simple. It doesn’t have the performance that the American and German tubes had, but you can make it. And we made thousands of them. It wasn’t broadcast that much after the war, it was broadcast a little bit. And they were used for a number of things. One thing, it was used in a thing called Tabby, which was a kit for driving. Now, it doesn’t need a brilliant mind to actually work out that the code name Tabby is not actually a terribly secure way of describing an instrument for driving at night, but somebody had a sense of humour. And the Tabby kit – this was actually two tubes side by side, so it gave you a stereoscopic view, and it was used for lorry driving and tank driving during the war. The other thing that was quite sophisticated, even more sophisticated, was a system for bringing spies back. We would land them on the French coast and the only thing they were
equipped with was a corner cube. A corner cube is a corner of a glass tube, a glass cube, which is cut off and machined, and it can be glass or it can be plastic, and this has the property that when a light beam falls on it, it is reflected back to exactly where it originated. So that if you shine a torch at it, you see a spot of light. You can see a spot of light, no-one else can see a spot of light, it’s a very narrow beam. So you can imagine that a spy could be issued with this corner cube and it can be in various disguises, it doesn’t have to be that visible because remember, you’re working in the infrared, and then if you want to pick them up all you do is you flash your searchlight, your infrared searchlight along the coast and you’ll see a spot of light, and that’s where he’s waiting.

Now what you use to actually do this is a very simple image converter system because it doesn’t need to require much current. It requires a few kilovolts of voltage but it’s not going to be a large current because all you’re doing is seeing a spot of light in it. And this is driven by a Zamboni pile. Now, a Zamboni pile is a pile of sheets of paper that have aluminium evaporated on one side and manganese oxide on the other side and it was, surprisingly enough, invented by a man called Zamboni. And this gives you one and a bit volts between the two surfaces but no currents, and there is one of these in some forecourt in somewhere in Oxford which has been doing this for hundreds of years, showing that it can keep a voltage up. It’s got to be slightly moist, but essentially it’s an electrolytic cell and all you have to do is to take these sheets of foil, and it can be aluminium foil that has manganese oxide evaporated on the other side, and you put a thousand of them together and you have then a tube that’s about this long – sorry, I have to say – it’s about a foot long and perhaps an inch in diameter, circular bits of foil. You press them together with a spring and you have a kilovolt of supply. And all you do is you put four of them together as the handle of an instrument and you’ve got four kilovolts coming out. You pop your tube, your RG tube on the top, and now you have an infrared imager which can give a picture and certainly can show you where somebody is waiting. And again, these were used. We had other instruments that were used, and they were used, whereas other nations did not get to the stage of using things in any detail, and this was simply due to the strategy which was a pretty brilliant strategy to say that what we want is something that works and it doesn’t need to be very sophisticated. I’ve probably got one somewhere.

Be interested to see one if you have.

I’ll have a look and see. Some of these have disappeared. I’ve certainly got some of the more complicated tubes and they weren’t made. Well, this is relevant, you see. And the other thing we were doing, and this is important [14:40] because it dominated my life for some years, is we were
making infrared photocells. Now these are for more complex systems where you actually have a material which generally was something like lead sulphide, though the Americans did a lot of work with thallium sulphide, what they called thalophide. It depends which part of the infrared spectrum you want to use. If you want to work out to about two point five microns you use lead sulphide. Thallium sulphide doesn’t go out that far. The RG tube that I’ve described, and that worked, that was called active infrared because you were using a searchlight to do this, and that was okay and it has applications. Of course it has its weakness in that if the opposing side has RG tubes or their equivalent themselves they can see what you are shining on better than you can see, more or less, because you’re relying on the reflection and they can see it directly. But if you’re using photoconductive cells, that is passive and that of course is the way things went. Well historically we can get to what’s happened. But it’s a different way of doing things, that essentially if you have a lead sulphide detector, you can detect warm objects. When I say warm objects, you can get a reasonable image from something that is probably one or two hundred degrees centigrade with a – you can actually detect hot objects with an RG tube, red hot you can detect. It’s something above 600 [°C] you can see in a near infrared system. Those will go out to about 1.1 microns. And we were developing lead sulphide cells and they were being developed at the Admiralty Research Laboratory in Teddington. Haslemere was also working on infrared and they were working more on the systems which would rely on Teddington to supply photocells. The Germans were also using lead sulphide. The difference was that they were using crystals of lead sulphide and they had, the top contact was a thin wire mesh, so they were called Netzcelle – N-E-T-Z-C-E-double L-E. I think it’s a ‘C’, may be an ‘S’, but they certainly were called Netzcelle. We know because we got some. The Americans had moved over. They also were using, you can use also things working at even longer wavelength and those are thermopiles, which the Americans did quite a lot of work with. And you can get a picture by having a photocell at the focus of a mirror generally, it is possible to have a lens, but obviously if you’re going to work at the very longest wavelengths you need a material in the lens which can transmit the radiation. The Germans did have such lenses. These were made of arsenic trisulphide and also a material called KRS5. KRS5 was [Thallium Bromo-Iodide] I think it was… that was probably a mixed crystal. But anyway, we generally, and so did the Americans, used mirrors because mirrors will obviously focus infrared independent of wavelength, you don’t get any chromatic aberration. If you’re working out to two point seven microns you can use glass or quartz. Now, that meant that if we had these systems there had to be a coordinating organisation to actually arrange the production of the searchlights, the infrared filters on the searchlight, the RG tubes, the Zamboni piles - if they weren’t using a Zamboni pile you had to have a power
supply that gave you six kV and you can imagine the lens systems, these were done, plastic lenses were used quite a lot instead of glass lenses because they were cheaper, and all the things. And so there had to be a headquarters organisation to turn these things out. As far as I know, this was all done by the Admiralty working with the Ministry of Supply. The Ministry of Supply would actually do the production but the infrared design work was done by the Admiralty. I had mentioned to you earlier, I think, that the Admiralty had taken on the responsibility for electronics research and development – and we will get to that later with CVD, and CVD may well have been involved at this stage but I wasn’t aware of it. I was asked to report to an office, which was the infrared [21:10] headquarters in the Admiralty. And it was run by a man called Milsted – M-I-L-S-T-E-D. We did not use first names, he was called Mr Milsted, and Mr Milsted when I reported seemed to have some other things on his mind and I later discovered that he was an executive in a company called Webb’s Crystal Glass and that was being set up and he was obviously going to leave and run or be a senior person in Webb’s Crystal Glass. So that was his interest. There was another person permanently in the office called Mr Carter. I wasn’t sure what Mr Carter’s background was, he was very friendly to me and everything went perfectly smoothly, but essentially he wasn’t technical. Milsted had technical knowledge. He had quite a presence and must have been quite senior. And he told me my task was to be, to read all of the reports that were coming out now from the Americans, the final reports on their government contracts which covered the whole of the infrared spectrum, and I don’t mean the infrared spectrum from wavelength, I mean the spectrum, from all the topics that were going on. And there was an amazing amount going on and I said, ‘What do I do with it?’ he said, ‘Oh, when you come out with anything interesting you go down to Teddington, which is our main research place, and you tell the people there what you have discovered’. Now, I was a callow youth of twenty-one, but it occurred to me that if I’d been working on infrared throughout the war I would not wish a lad of twenty-one, wet behind the ears from university, to come and tell me what I had missed. So I never told anyone anything. I certainly went down to Teddington, but I listened to what they had to say and they were all quite anxious to tell me what they had been doing and where they’d got to and they would want suggestions, but I never told anybody what was happening. Another job I had to do, and this again is interesting, I was twenty-one, I had to interrogate Germans who we were bringing across. Now in fact, the group at Teddington, which included some pretty good scientists, was going across to Germany then and seeing what was going on in the laboratories, as was the equivalent lab, TRE, which did have some infrared interests which developed much more later on. And they even brought back an infrared spectrometer that was made by a firm called Leiss – L-E-I-double S – and was a brilliant instrument, and they arranged to reproduce it. And it
was reproduced and we all used them. But they were essentially, the design was stolen from the Germans. There were other things we stole from the Germans too, just like that. But I had a bit of German, I’d say. I hadn’t actually mentioned this, but curiously enough, I did mention that I had really prepared for the LCC examination and one of the things for the LCC examination as opposed to the higher certificate was languages, so in my first year in the sixth form at school I had carried on doing French and German, which the others had not done. And that kept me in good stead when I had to do my degree, because at that time in the degree, one question in each of two papers was in a foreign language. It wasn’t a difficult question I will say. In one it was French, in another it was German, but it did mean marks and as a result most of the people could do the French, none of them could do German, except I could because – I had a pretty good German master, Mr Gee – G-double E. He had a big red moustache, he was quite a character and he carried us through our German quite well. So I had done German and French for my O level and had carried on doing them for one year and I kept on doing French as a subsidiary in my higher. I had dropped the German by then, but not completely, so at college I was able to do a bit. And this meant I had a smattering of German, enough so I could understand some conversation. [26:55] And I had to go to Wimbledon occasionally and join in the interrogation of German scientists who were brought across at twenty-one, crazy. And it was quite interesting and I could, I found I could sort out their characters. I can remember there was a gentleman called Wesch – W-E-S-C-H – who claimed to have the best infrared detector ever, which was based on a dielectric, it was a capacitor, it wasn’t a normal photocell of some kind like most people had, like a thermocouple or something like that, this was the Wesch system, but I took against him, I didn’t take to him much. He definitely seemed politically not the kind of person I would like. And it so happened that the device really didn’t work much and I was pleased about that. I also came across a paper that had been written on the transmission of infrared in a cloudy atmosphere. I came across this first in German, but then discovered that the Americans had translated this. This all is extending through ’45 and ’46 and I have to say that I didn’t feel I was completely engaged in work, I had quite a lot of spare time. So I decided to write a book. I got interested in what – I’m trying to think of the name of the man who wrote… I think it began with a ‘W’, I can’t remember. I did meet him later on actually. But I felt that this, what he’d written was more a pamphlet, was quite short and you needed to do much more going back into the physics of it as to… it wasn’t sufficient just to say what happened, you had to say why it happened and what there was. So I started writing, essentially a treatise on the transmission of infrared radiation.
Why did the subject interest you?

It obviously was relevant to there, I was being given quite a lot of background and almost anything I studied. But I went into the scattering of radiation and the absorption of radiation in the air and in different, and the composition of atmosphere, and I was able, we had a very good library to look up a lot of the references, and I had pretty good relationships with Teddington by then because I hadn’t been stupid in our interaction, so I got to know the people and we got on quite well with each other. And eventually this was issued as an ARL report – ARL-R3E600 – and I still regret the fact that I loaned my copy to somebody who never gave it back, and I can’t remember who it was I loaned it to. But that was my first publication. Or it wasn’t published actually, it was the report, but it was about that thick, an inch thick… no, half an inch thick. And was a good report and it had a lot of good stuff and it was good for me to do this and I did learn quite a lot, which will come up later on. So I learnt about what the atmosphere was like and about scattering of radiation and there was a bit of meteorology in it and I learnt about clouds and what there is in clouds and fog, how you measured droplet size and things, and it was okay.

What sort of response did you get from your colleagues at the time to writing this?

Oh, they were very pleased. It wasn’t a bestseller, but it was, it was used by all of the infrared groups and was something that hadn’t been done before. I mean the information was there if you cared to do it, but it hadn’t been assimilated, hadn’t been worked out, and there were some quite good graphs in it that they could use. So that was how I spent some of my time.

What sort of criteria are you using to interrogate the Germans? I was interested when you said you didn’t like his politics.

Well I didn’t lead in it, of course. There were senior people doing the interrogation, but I was doing the interrogation from the point of view of the infrared they knew, and some of them knew a lot and some of them didn’t know very much. But I learnt some interesting things. For instance, I did learn from someone, I don’t remember exactly how I did this, that they actually had detected, they got – I said they’d had some infrared equipment, and indeed they had some very large and sensitive equipment mounted, I suppose it was on the Cherbourg Peninsula - and they had just about got this going by June and it detected the flotilla of ships coming. It was perfectly capable of doing that and it did detect them. But unfortunately the operator had
previously, a week earlier, reported that he could see a lot of targets and the commanding officer
wasn’t impressed when he later – nothing happened – and he later said that well, that was a loose
contact which he had now mended. But he, this one he really did detect and when we looked at
the equipment there was no question he could have detected it, but the commanding officer
thought he’d got another loose contact so nobody took any action. What action they could have
taken I don’t know, but anyway, there was no question that he did detect it and in fact we later
had that equipment brought back to England and was used. [34:10] Not to detect flotillas but for
a different purpose. So…

*What sort of set-up are the interrogations as well? Are they sort of informal chats over a…*

It was in a school in Wimbledon, I remember that. You just would have two or three people.
There would always be a translator there, but it helped to have a little bit of the language. Some
of them spoke quite good English and it wasn’t necessary, but I took part in probably half a dozen
or more interrogations. So there was that side and meanwhile I was acting like a sponge in taking
in all this information coming out from the Americans and, I mean it was ridiculous, I mean there
would be each day three or four reports, each maybe an inch thick, because all of the people
writing them were trying to justify the money they’d had for their research, they were pretty
thorough. A lot of them would duplicate each other, but they were different places, so I got to
know a lot of the different laboratories and the people working, I got familiar with the names and
what was going on and after a year I probably knew more about infrared than anyone else in the
world, generally, because I would cover the whole of the things. It was just like a sponge taking
it all in.

*Can I ask a few clarification questions about some of the things you’ve mentioned before we go
any further, just for people who, you know, may not know what infrared is, have got a way into
this as well. And I was thinking, what’s the advantage of using infrared over normal visible
light?*

Well, there are two advantages. In the first place, if you’re using it to illuminate a scene, you can
see and the enemy can’t. So that’s the first thing. So, I mentioned Tabby, so you can drive at
night, you can’t normally drive at night because you haven’t got headlights, because if you’ve got
headlights somebody can see them and can bomb you or shell you, but if you’ve got infrared and
they haven’t, and most people didn’t have, then you can drive and they can’t. You can also use it
for secret signs and things. Something, a code that’s behind a piece of plastic, the piece of plastic
lets through infrared, it looks like a piece of plastic to you, you shine your torch on it when
you’ve got your infrared viewer you can see what the sign says. So you can use it for your
navigation. That of course is for active infrared. For passive infrared, almost any thing that is of
military significance is warm. People are warm, any engine is warm, any piece of metal that’s
been left out in the sun becomes warm and many things will still become warm at night. So if
you can actually detect, and better still image the radiation that’s coming off from a cool object,
which will be different from the radiation coming out from a cold object, then you have a way of
seeing at night, which other people won’t have and we call this thermal imaging because it is
warm. Now today this has reached an enormous degree of sophistication so that you can actually
buy these instruments for commercial purposes, and they are quite useful for a number of
applications. For instance, if you want to, if you think that in an electricity pylon there is a
contact which isn’t very good, it being very good, not being good means that it’s got a higher
resistance than it should have, that means you’ll be developing more power in it, so it’ll be warm.
Well, I can look at that with my thermal viewer and I can see it from the ground. There’s no other
way you could see it and you can’t go sort of touching all these things and going all the way
along and doing it. I actually had to use a system and in fact this was using an RG tube system,
though it was by then more sophisticated, when a company – a company – it was the Gas Board
in Birmingham, was worried about one of their containers, I don’t know what it was, and they
asked if I would come and look at it. So I came and looked at it and said, ‘There’s a crack’. And
they said, ‘What do you mean there’s a crack?’ I said, ‘You can see, there’s a crack here’. He
said, ‘I can’t see a crack’. I said, ‘Well look through this’. And he looked through the infrared
system, there was clearly a crack and because what was in there was hot, it was warm in coming
out and you could see it. So you can use it in chemical processing places, you can use it on any
kind of moving object, such as a rail joint, a joint in a car, you are trained to see it, your bearings
aren’t working properly. Anything that’s likely to get warm. And of course you now use them
almost routinely in looking at airfields and military targets and things. The other point is that you
can see things after they’ve gone, you can actually see a place if something’s been left, and then
it’s moved out, you can see where it had been parked. So thermal imaging is a standard military
technique, but of course we didn’t know this back in 1946.
Back in 1946 as well, I suppose most people are familiar with looking at infrared pictures now, through TV for instance. I’m wondering what do you actually see, what does the image look like at the back of one of those tubes?

Well, what it looked like in the simple RG tube is it was green. In fact that was quite difficult to get across to military personnel. Generals and people when you showed them this, they said why do you call it infrared, it’s infragreen. And you said, it’s not actually infragreen, it’s infrared. But that depended on the phosphor you used in the tube, but generally zinc sulphide was the phosphor and generally showed up as green, so it’s a yellow-green, but it is greenish. That’s what you see, and it wasn’t coloured. When you do it by scanning the colour you see, I mean you just used the cathode ray tube, a colour tube, and then you can put any coding you like in the colours, and what you normally will do is you will have a scale of different colours and you will try and get them so that the hotter it is the redder it looks, which is just a convention, it doesn’t have to work that way, you could do it the other way. You could start off with it in the blue, but in general it’s done so that you get a range of about ten colours in which red is the hottest and blue is the coldest. But you will see a colour picture. But of course it isn’t a colour picture. I mean the radiation that’s coming out obviously varies. But then we were trying, we were trying to develop images, but they were more by scanning rather than by having an area that you could see, but we will come to the developments in that later on because that is how I got my PhD.

What sort of resolution are these images, as well I was wondering?

Oh, the RG tube had very good resolution in the centre. It was understood that without any electron optics you could not get a perfect image, but in the centre of course there were no aberrations because I said that it was a one-to-one correspondence and if you put 6kV between the two surfaces that are a couple of millimetres apart, the electrons from the photocathode will go straight across to the phosphor screen and there is no deviation, you’ll get quite high resolution of well, several hundred dots per inch effectively, it’s a good picture. But as you come away from the centre, you will clearly see distortion around the edges, because the electrons now can spread out a bit, they don’t have to go straight across because your field is no longer exactly orthogonal to the surfaces. So you will get a region in the centre where the resolution is very high and then as you go further out all the way round you will start seeing some distortion which is probably pincushion distortion. But that isn’t how you use the tube, because of that you tend to
use the bit in the middle. The scanning tubes, the resolution will not be that high because if you’re trying to get a lot of lines per inch, it means that you’ve got to scan lines very close together and it just takes you much longer to build up a picture by which time the picture’s changed, so you won’t get a high resolution picture but you will get quite a lot. I can show you some pictures.

[45:10]

That will be great. Just as well, what’s a photocell, briefly?

What’s a photocell? What is a photocell? Oh, it just is a tube that is, it’s generally applied to a photo detector. It essentially is a sensor of light, so it can be at any wavelength. It’s not generally used for X-rays and gamma rays, but once you get up to the ultraviolet and then through… it’s not generally used once you get up to what you might call the radar frequencies, but if something could detect terahertz, you probably would still call it a photocell. It’s, I suppose it’s short for photon cell, where you’re detecting a photon and those photons may be of any frequency of any wavelength, but it is, it’s commonly used for the visible but people talk about infrared photocells.

Shall we break for lunch as it’s…

Yeah, we’d better.

…half one.

[end of Track 5]
I was wondering if you could tell me a little bit about what it was actually like to work in your group at Fineman House, Fenniman House?

At Fanum House.

Fanum House, thank you.

I was on my own. The only other person who really had some knowledge of science was a man called ER Freeman. I can remember his initials, I don’t know what his name was. Curiously enough, I did find out he lived in Pinner and that was the first time I’d heard the name Pinner, and then I came to live here myself, but I haven’t been able to locate him, not that I’ve tried. Well, he would be dead anyway. He was alert and more concerned with me than the other people were. Milsted, as I’ve said, had other interests and he was happy that I was doing the job that he wanted done, I mean with the interrogation in general he’d look after. Oh, I also had to look after our consultants. We had several consultants, quite famous scientists who it was good to get to know and that was useful later on. There was HW Thompson from Oxford who was a distinguished spectroscopist but also ran the amateur football team there that was a combination of Oxford and Cambridge. I forget what it was called, it began with an ‘A’. But they became quite well known and did actually enter for certain prizes. There was JW Randall from Aberdeen, I think it was, it may have been St Andrew’s, who had come down to King’s and later ran the group which eventually worked with Crick and Watson on DNA and Randall was a known spectroscopist. There was Gordon Sutherland who was at Cambridge, and there was Rollin, forget his first name, who was doing a special kind of infrared detector. And I was basically supposed to liaise with them and check that everything was going well and they were getting all the help they wanted and were liaising with people, and in fact there was a problem or two with them using our library which I had to sort out, which the librarian didn’t want them to do and they wanted to do it, but it was all okay. That was my main connection with science, except for linking with the people in Teddington, and also with the people in Haslemere who were doing ship trials and things at one stage, seeing what you could detect from ships’ funnels, which was quite a lot actually, because nobody was taking care to cool them. But I still had a lot of spare time and Freeman was a bit concerned that I was spending too much of my time wandering around Soho, not that I was getting up to any mischief, I was simply observing the population, but he thought that was not
great and I should have more scientific stimulus. So in the end he arranged that I should actually be transferred down to Teddington and I would work in the infrared group there.  [03:50] This was fine as far as I was concerned. I’d more or less finished my book and I started getting involved in the work on infrared transmission. Now, I knew much of the background and what was happening was that the Germans had effectively discovered what was called a window in the atmosphere, and a window is something which means that radiation is transmitted through. It had previously been thought that the best window in the atmosphere for intermediate infrared, which is where photocells worked, was about 2.4-3 microns. There was a window at 1.8 microns. The atmosphere is full of water vapour absorption bands, in spite of what you think about climate change and things, CO₂ is a pretty minor atmospheric constituent, it’s water vapour that does most of the problem. And it’s the bands in between that you can exploit. And the Germans had discovered one between three point four and four microns and nobody knew about this, it hadn’t really been revealed much, so it was decided that ARL should set up a project to measure the atmospheric transmission throughout the infrared spectrum. I was an extra body I suppose and I got involved in the measurements and after a time I got involved pretty strongly, particularly in the analysis of the results. This involved us going up to Tantallon in Scotland. When I asked I was told this site was one of, there was an Admiralty station up there called HMS Tantallon which is near North Berwick and it’s just opposite the Bass Rock, and I was told that this was where there were more fog-free days every year than anywhere else in the British Isles. I found that a bit difficult to believe, but that’s what I was told. I’m trying to think of the timing of this but I think it was about 1947, which slightly complicated my domestic arrangements because I’d just got married and we’d got a flat in Streatham near my parents. But Betty was working, Betty had been working first at the Elephant and Castle, which did not prove terribly successful, but then she got work in Croydon at the Girls’ Public Day School Trust, which was much more to her taste. And I would go up to Tantallon for two weeks or so at a time and help in the measurements. The mainstay was our technical officer, Walter Harding, who died a month ago at the ripe old age of ninety-something, though he’d been not terribly well for the last ten years. But Walter knew absolutely everything about optics and laboratory practice and mirrors and everything, so it was very easy working with him. And essentially what we were doing is setting up a system that sent a beam of visible and infrared light a distance of about one sea mile, 2,200 yards, at least I think that was the distance, that was the optical path. Maybe it was 1,000 and the optical path was twice that because it was reflected back. And to do this we had two huge parabolic mirrors which were mounted in frames so they could be moved and oriented in different directions so you could get them accurately aligned, which you needed to do if you were
sending a beam half a mile and getting it back and it had to come back exactly on the centre of your detector. And these were barrels and mirrors that had been looted from Germany, from the equipment that had been on the Cherbourg Peninsula, and this was called a Donaugerät – D-O-N-A-U-G-E-R-A umlaut-T – and was meant to be used for detecting military vehicles; ships, tanks, anything. But we had it just as a mirror system and things and we set this up and were measuring the atmospheric transmission. We also were comparing it with the visible. What we were trying to do was to see how the infrared transmission, not depended on the visible transmission but could be monitored by the visible transmission, and in particular we wanted to check that infrared radiation could only penetrate further than visible radiation when the visible range was long.

There was a story that infrared went through fog, and indeed, at the headquarters, almost every day they received a suggestion from the public that they had a new system for military use which involved the use of infrared because it could see through fog. And they had to have a rubber stamp prepared, which I have now, which said, ‘Infrared does not penetrate fog’. Now the point is that if you had my book on infrared transmission you would know that essentially the reason why you can’t see through fog is because of the size of the fog droplets and the transmission or the scattering of radiation in the atmosphere is governed by essentially the laws set out by Mie – M-I-E – not by Rayleigh. Rayleigh did the work on very small particles, on molecules, but in a fog, well let’s start off. Say, as the visual range decreases what is happening is that the cores in the atmosphere, the salt cores or soot cores gradually get a coating of water on them which increases their size and the scattering of radiation from these cores of whatever plus water will depend on the diameter of the particle. And when the diameter of the particle is the same as the wavelength it will scatter intensely, but it won’t scatter much until that’s the particle size. So if you have a particle that is about one micron in size, it is perfectly true that infrared radiation of two, three, four, ten microns will go through much better, but as you increase the size of the particles, as you do as you’re moving from a haze to a fog, so the particle size is increasing, which means that it is now commensurate with your infrared wavelength. So your infrared wavelength is scattered just as much as the visible radiation is. So while it is true that if you have a very thin haze during which you can see, say ten miles, in the infrared you can see forty miles and people took infrared photographs to actually prove that, which made people think that infrared went much further than visible, which it does when the visible is also going a long way. But as the visible range decreases, the infrared range decreases more, until when you can see ten yards you might be able to see ten point one yards in the infrared, but that’s about it. But, infrared does not penetrate fog just at the time when you want it to. But what we wanted to know was what was the dependence over a period of time as you changed the things and we did this
pretty thoroughly in there. And I was essentially helping with the measurements until [13:30] we then realised that we would be much better off if we could have a longer path length as well. So we put another shed on a promontory and had two path lengths; 2264 and 44 something, not exactly twice, but near enough twice so we could do measurements across both. And we did all these measurements and we measured the visual range and everyone was very happy, but we knew that the mirrors deteriorated in time, being exposed to the sea salt, that the mirrors had to be carefully prepared. You prepare them by putting a chromium flash down on your glass before you evaporate your aluminium on top, which means they’re bonded much better. But they still age and at the end of the trials we suddenly realised that we did not know how the reflectivity of the mirror had changed with time. And we were at our wit’s end until I realised you ought to be able to from the data we had in the visible, we ought to be able to calculate what the reflectivity was. And I was a hero, because you then could do it and our results could be rescued, which they were. And I also was able to, from my knowledge of scattering and things, which is what I’d worked on of course for the book, which is why I was so useful, I was able to essentially write the section of the publication on interpretation of the results as to what it meant and what essentially the particle size was from this. And that was very satisfactory and we published it in the Proceedings of the Royal Society, which was my first proper publication. In fact the team wanted my name to go first, which was a great compliment, but the Royal Society said, even famous people accept that the names are in alphabetical order in the Royal Society. Which irritated the man who was running the thing, Aubrey Pryce, by then because Alastair Gebbie had really started the thing and it was quite reasonable that his name should go first, but he and Aubrey did not get on terribly well later on and Aubrey didn’t actually want Alastair’s name to go first, but Alastair’s name did go first and it’s Gebbie, Harding, Hilsum, Pryce and Roberts, in strict alphabetical order. Vernon Roberts looked after the electronics and the interesting thing is Vernon was at the Malvern lab which had collaborated with us. So things were pretty good and we were pretty happy with that publication. We had got out another publication earlier and this had been largely Alastair Gebbie’s work because he had realised that an artefact we had seen was not an artefact, we had noticed that there was a dip in the transmission near 3.67 microns and we couldn’t understand this at all and thought it was an artefact, but he pointed out that this was half heavy water, HDO, which had not been seen in the atmosphere before. You don’t expect to have much HDO or deuterium, D\textsubscript{2}O in the atmosphere, you think that it’s all H\textsubscript{2}O, but if you’re measuring atmospheric transmission over a path and you’ve got this very intense absorption due to water vapour, you will get intense absorption due to D\textsubscript{2}O and also to HDO. And Alastair pointed this out and he was quite right and we did some calculations and showed that. We had actually
detected HDO in the earth’s atmosphere, which was the first time, so that was actually my first publication. Not that I knew very much about it, but still, I had done the measurement with water so it was reasonable my name should go on the publication, but that was largely Gebbie.

[18:05]

Who were the other people you were working with altogether on this?

Well, those were the people. Gebbie, Harding, Hilsum, Pryce and Roberts. Vernon would come up and get the electronics working, then in general I’d be doing it with Walter most of the time, I’d taken over from Gebbie. Gebbie and Walter had done the original work but I did, with Walter, most of the work, though Pryce came up occasionally to supervise. It was a communal effort, but it took us a long time. It took us well over a year in the actual measurements, sort of in bits at a time. One of the problems was we discovered early on that the noise level of the system was very high during the day with sun on the atmosphere, that you get too much, well, variation in the optical path because of the temperature changes, and it wasn’t easy to take measurements. So we actually had to do most of the work at night, which was okay, there was no problem in doing the work at night, but when did you sleep? Well I slept during the day and I don’t know when Walter slept because he was mostly getting the equipment working again during the day. And then he was playing golf as well, so I think he just managed for three weeks without sleep. But it was quite good and also we discovered that up in Scotland rationing did not have the same meaning as it had in the south, that you could get very good meals out and you could even buy Nescafé and I was popular with my mother and Betty with bringing back tins of Nescafé. You had to beg for a tin of Nescafé in London, but this was a time that you could get, you were beginning to get Nescafé, you couldn’t get it before, but here you could go into a grocer’s shop in North Berwick and say, ‘Can I have a dozen tins of Nescafé’ and they’d say, ‘Yes, of course’ and you’d have a dozen tins of Nescafé which you put in your suitcase and brought back. And it seemed all perfectly legal, no black market, it was all shown in the window of the shop, but back in London it was under the counter and they’d give you one if they liked you. So there were some benefits and it also was clearly a benefit because our names became known and it was quite a fundamental piece of work which was quoted for many years afterwards and still is to some extent referred to. And that was ’49.

What were you actually doing the measurements with? What do you use to measure?
Oh, that was pretty simple. You have essentially a source of infrared and that means you’ve got to have a very hot filament and no, well in principle, no enclosure. Now, you cannot have most metals in air and heat them up because they will oxidise and essentially they will break, but there is a thing called a Nernst filament which is slightly related to a gas mantle. You know that you can have gas mantles, gas flames, and the mantle around it is made of an oxide which itself glows quite hot and lasts for a long time. It’s very thin and usually gets damaged more by touching than by anything else. Well, a Nernst filament is essentially a rod, a thin rod of thorium oxide which you can pass a current through – I think you have to heat it first, it’s not a terribly convenient thing because it has to be heated before it becomes conducting, once it’s conducting you then can increase the current through it. But you cannot sort of do anything with it while it’s cold because then it is an insulator. So that’s your source and that gives out a spectrum that’s a black body spectrum essentially for a body at something like 1100°C, and that gives you plenty of visible and infrared, though the visible is measured in a different way, which I’ll have to come back to. But it means that you’ve got a wide spectrum of infrared, including quite a lot of visible radiation.

The detector depends on which system you find most convenient. What you want is a detector which has the same sensitivity throughout the spectrum, otherwise you’d have to calibrate it, which means it must be like a black body and what we used was a thermopile that had a black coating on it, a gold-black coating. But there are a range of detectors that you can have and of course you can always calibrate them if you know the temperature of your source, you can actually work out what the sensitivity variation of your detector is across the spectrum. But you do have to have something which will cover the whole range, in our case from the yellow through to fifteen or sixteen microns, which you can do. There have been a lot of people working on the infrared for many years. So that was all straightforward. Then you need a decent amplifier and that was where Vernon came in because Malvern were much better at electronics than we were, so they had some of these amplifiers that could be used. [24:35] And the whole thing was on recorders. For the visible we used a different system. That was a telephotometer, basically, that what you had was a telescope that was adjustable in its focal length and in it you had an illuminated screen and you looked through the telescope at a, illuminated screen that was very white and then you did what you normally do with a photometer, you turned your local screen that you could see in your eyepiece up until it matched in brightness the screen you were looking at, and you then could measure what its brightness was. You then moved the screen to your shed a mile away and again looked through with this telescope, and now you could do it because it was the telephotometer, and again you adjusted your local brightness until it matched it and since you knew it had been set up with the same brightness as it had had locally, any decrease in brightness
must be due to the transmission of the atmosphere at 0.62 microns, which is, you used filters so that you were doing it at a narrow wavelength. So that was your measurement of visual transmission which was used as the monitor.

*Just to summarise, we’ve talked quite a bit about this in detail, but in a couple of sentences, what’s the key finding of this experiment?*

The key finding was that the Germans were right. There was a transmission window in the atmosphere, but what was more important was we now had a way of actually judging what the transmission was going to be at any wavelength, so we could design optical systems for the infrared knowing how well they were going to perform and exactly when you would start losing performance simply by a knowledge of the visual range. I mean it’s fairly easy, there are standards by which you can tell what the visual transmission is, because you know at which distance you start losing your visibility of objects, so it’s relatively easy for you to work out what the visual transmission is. It is not easy to know what the infrared transmission is, but we had shown by the link between them just what it was – approximately – it wouldn’t be the same everywhere because it would depend on the humidity, but there was likely to be the same kind of connection that we had discovered. So it was very useful information. And that was why we had done it, obviously. [27:45] What I haven’t said is my own position in this, that essentially I had come to Teddington as a Temporary Experimental Assistant grade three, which put me at the bottom of the pile. But there was now a competition, open competition for scientific civil servants at the beginning of 1947 and I entered that and I think I have mentioned the interview I had as the examination which finished up with me playing a chess game with the – haven’t I mentioned this? Oh. You obviously put in a CV and a resumé of what kind of things interest you and what you have done and I put down on my resumé that I was very interested in chess, in playing chess. Now, chess is the kind of thing that is very respectable, is the kind of thing that’s very respectable, and there must be many people who put it down really to sound respectable rather than because they play chess, I realised that afterwards. But when I went up for the interview after the normal things of saying what I had done the chairman said, ‘I gather you play chess’, and I said, ‘Yes, a fair amount’. He said, ‘How much do you play?’ I said, ‘Well, I do play for the ARL team which is part of the NPL team and I can play locally for the National Physical Laboratory’. And he said, ‘Well what would you do if I played pawn to queen 4’? I said, ‘I’d do pawn to queen 4’. He said, ‘Pawn to QB4’? ‘Pawn to K3.’ ‘Knight to QB3?’ ‘Knight to KB3. Pawn takes pawn.’ ‘Knight takes pawn.’ ‘Oh.’ And then someone interrupted
and said, ‘How long are you two going to play this game?’ and the chairman sort of looked around, said, ‘Well, I thought I was doing all right’. And they said, ‘That wasn’t the point, this is not quite why we are here’. But that was all right, that put me in quite well. I did play chess, I mean I hadn’t put it down to seem good, I just liked playing chess and I had played since school. So I did pass and I did wonder at the time, because as far as I remember, the pass mark was 240 out of 300 and I was told in the written examination I got 245. Now there was, when I’d got the results, which were printed results which were sent through, I was pleased obviously that I had passed, but there was somebody from Haslemere I think it was, who had got 275 and I thought golly, he must be good. Never heard anything of him afterwards. I did quite well in the Civil Service, I never heard about this chap who’d got thirty marks more than me, he must have been very good. Anyway, I passed and now I was a Scientific Officer, which was quite something and it certainly meant my salary went up by quite a lot.

Comparing the two sort of different position - Temporary Experimental Assistant third class?

Yes.

- on one side and Scientific Officer on the other, what's the difference in the sort of work you're doing and the way that other people treat you?

Well, it’s other people trust you to do things. They can give you different things, and to some extent you’re then in a position where you can actually run staff. I mean as a temporary Experimental Assistant I could not have had other people reporting to me, I could not have taken on students and things. As a Scientific Officer, yes, I had a responsibility, definitely, and had a position and could in fact even get promoted, though I must say that did not happen for some time, but we’ll get to that. And it also was a permanency. The ‘T’ in front of EA3 really meant temporary and I could be given the sack at any time. As a Scientific Officer I was part of the Civil Service now and I even was down for a pension, not that I ever knew about it, but still I would have qualified and did, though actually I was in pensionable employment. I was respectable now. So, and I was doing my own things and was encouraged to do my own things. I wasn’t obviously the top person in the group but I was working my way up in the group, as will become apparent, because other people who’d been with the system through the war years were now taking other jobs. We had two quite well known scientists who had been involved in the
infrared group: Ted Lee, Dr EG Lee, and Arthur Elliott, and both of these now left to go back – they left before I joined – and Tom Pratt was running the group. He was not such a well-known scientist but he was very capable. Alastair Gebbie was still in the group, Aubrey Pryce had come along, there were a few others and there were two Polish scientists who had joined during the war: Jerzy Starkiewicz - and you won’t expect to spell that – he was known as George, and Frank Kicinski. And we will come to them because they are important later on in the group and there were a few others, there was Doug Phillips. I can’t remember any – oh yes, there was Louis MacNeice who looked after systems. And we did a lot of testing of photocells and really trying to design systems that were more sensitive. But it was more a question of actually working rather than being responsible for strategy.

When you say the group, I’m interested in how this group actually functions.

Well, there was a group leader who I said was Tom Pratt, who would be reporting to the director or the deputy director of the Admiralty Research Laboratory. The Admiralty Research Laboratory had different groups, most of their responsibility was underwater acoustics because this is what the Admiralty specialised in, which was submarine detection and countermeasures for our own submarine against detection by ultrasonics by the enemy. So that was a large requirement, but because of the Admiralty responsibility for electronics this was why we had finished up with an infrared responsibility for the services for at least the photocell parts and things. Though as I say, ASE was interested in ship detection and we did work with them.

Where is the group actually located?

In Teddington, in Queens Road, Teddington. The buildings are no longer there because - they were there until about five or six years ago. The establishment had a common barrier, boundary with the National Physical Laboratory in Teddington and we shared some facilities, like the canteen, with them and our sports club was amalgamated with theirs and was a division of NPL. This proved quite interesting later because I realised I had played chess with Alan Turing, who was, I think their computer science was part of their physics and he played for them and I played for ARL and we had inter-division competitions. I knew he worked on computing, I didn’t think anything strange, I was a bit naïve then about relationships so I didn’t think he was at all odd compared with many other people. I did beat him at chess, which was okay, but it wasn’t
anything remarkable. But I did know what he was doing and I was very interested in some of their work. They were working on the first computers, you spoke to Wilkes, but of course at that time NPL was doing a lot on the early computers, particularly on delay lines and memories.

*How much of that work was known about in your own establishment?*

It wasn’t secret. What we were doing was certainly secure. The photocell work was not published. The atmospheric transmission was obviously published, but much of what we were doing on infrared materials was in the public domain and as far as I know everything that NPL was doing was in the public domain. But all Turing’s work was now public. The other person who worked with him was Leslie Fox who became a professor later on. He was a very good runner.

*What sort of chess player was he?*

Fox? Didn’t play chess as far as I remember.

*Sorry, I mean Turing.*

Turing? He was okay. I mean I was sort of reasonable county standard, reasonable county. We would play occasionally for the county and I would win sometimes and lose sometimes. Turing wasn’t as good as that, probably because he wasn’t that interested in it, he would play much more for social reasons.

*Are there any other links between the work that you’re doing for the Admiralty people and the work at Teddington?* [39:30] *Are there any sort of work links, for instance, common meetings, that sort of thing?*

Well I was now in Teddington, remember I had actually…

*Sorry, I meant the NPL at Teddington.*

No. No, there was… NPL had a physics group. Later on they started getting more into the kind of materials work that we were doing, but at this stage no, as far as I know they weren’t working
on anything like that. They were working on new methods of making gratings, they were obviously doing the computing, but I didn’t really know very much about what they were doing scientifically. We didn’t have that in common, we just were sort of neighbours and could join in socially. I did run for them. I mean, they had an athletics team and we’d have matches and I was running in the 440.

*Interested as well, talking about working in a group, are you working as an individual on your own little project in the group or working more closely with those around you? Give me an idea of the sort of dynamic between you all perhaps.*

I think I would have been given a job to do, but not how to do it. I certainly… now I’m trying to – oh, I can remember for instance that when we discovered the line in the spectrum that was, we thought, HDO, it was my job to confirm it experimentally and repeat that absorption spectrum in the lab. So I had to design an experiment to do this, which was an utter failure, because I thought the simplest thing – you obviously could get heavy water, I mean you just could buy DTO. It was a small tube, I mean you didn’t get a jugful, you got fifty ccs, and I realised that what I had to do was to dilute this by fifty per cent with ordinary distilled water and then put it into a tube which I would then evacuate and then measure the transmission. Now, it was obvious that you couldn’t have an optical cell that had glass walls, so I got a tube made that was probably about a foot long and was about four inches in diameter, and had plain ends that I could put a quartz plate, and that would be quartz that again you just could buy, and then I’d evacuate the tube and let the D$_2$O sort of expand, evaporate into this tube and it would be full of HDO and nothing else. So I set this all up and the pump working and evacuated the tube and the quartz windows broke. Of course people came in when they heard the breaking and said, ‘Hm, you haven’t read Strong’. And I said, ‘No, I haven’t read Strong. What is Strong?’ And they said, ‘It’s in our library’. So I went to the library and found John Strong, *Laboratory Practice* and it said that you can hold a vacuum in something if it’s plane [with thickness that is one third] of its diameter and if it’s under one-third of its diameter, it will break. Well, mine was like one-tenth of its diameter so it wasn’t surprising that it had broken. But this is if it’s plane. This of course comes in much later on when you try and design cathode ray tubes, because one of the problems with making a big cathode ray tube is that you have to have a thick face plate if it’s going to be large and it starts becoming very heavy, which is one reason why you never had cathode ray tubes that are as big as that, because if you think about the glass plate on the front, that would have to be very thick. Doesn’t have to be quite one-third because Strong points out that this is for something that is
plane. You can actually work with something that’s thinner if you have it curved and you will observe this in television tubes, that they are never plane in fact, they always are curved outwards, because that means the strain isn’t entirely orthogonal, it goes to the sides, so it’s better. But that was what I had discovered. And there was no particular reason why I had a tube that was that wide anyway, I think I had just found a tube somewhere and had done it and hadn’t thought about it. But it taught me that I really ought to read laboratory practice so that I knew something about it because nobody had ever told me about laboratory practice at college. I think GB Brown would have been astonished at the things you have to do when you work in a laboratory. Walter of course was quite scornful. He said, ‘Why didn’t you ask me when you did that?’ I said, ‘I didn’t know there was any problem did I? If I’d known there was a problem I would have asked you. I thought it was just simple, I put quartz plates at the end and pumped it out. I didn’t expect the whole thing to suddenly break in front of my very eyes’. I learnt a lesson and I had to put up with quite a bit of joshing later on. Whenever I did something, somebody would say had you checked with Strong, of course. Yes, I have checked with Strong. [46:45] Though in fact later on when we were doing more important things like making Christmas decorations, which involved the glassblower making beautiful spheres of glass and then we had to silver the insides and then we’d put a coloured coating on them that we dipped them in. The silvering the inside was done by using silver nitrate, I think it was, as a solution and it had been pointed out to me that this was a dangerous system, that silver nitrate formed needles which then were explosive and I should be careful. I didn’t realise what they meant by being careful. Anyway, it was my job after the weekend, that’s right, on Monday morning when I came in I was told I had to get them out from – they would have been silvered over the weekend, left to silver over the weekend – it was my job to get them out and get them ready for Walter to do the colouring of them. So I opened the cupboard door and moved the dish, the silvering dish, at which the whole thing blew up. Fortunately I only got my arm in the cupboard before it blew up, but I had all silver nitrate on my shirt which completely dissolved it over the next week or so, so that I lost my shirt, but I didn’t lose anything else. And again, people pointed out that, Strong says, ‘From hereon there is danger of an explosion’. And I said, ‘Yeah, but you can’t expect everybody to read all of Strong and take it all in’. I did then start reading Strong. It’s a very good book actually and he was a very good experimentalist. These are things which are not taught to people actually, that you, I don’t know of books in laboratory practice now that people have to read. I’m sure they have to go through a course but a course can’t cover everything. But working with these people, George Crockett was an excellent glassblower, Walter of course who dominated much of my life and I owe so much to him.
It does bring me on to the question I was going to ask about how, [49:25] how good was sort of technician support at Teddington? How much of it did you have, for instance?

There were two grades. There was scientific grade and there was an experimental grade. And the experimental grade were people like Walter. There were laboratory assistants but they were very young and they would be expected to get promoted or to – I mean, yeah, there were assistants and senior assistants. I don’t remember, I don’t think they would have got paid much so you wouldn’t have expected them to be any quality. But there were Assistant Experimental Officers, Experimental Officers and Senior Experimental Officers. The Senior Experimental Officers would be very senior and you didn’t have that many of them. The EOs were pretty good people who helped you a lot. We didn’t have many. I didn’t have anyone working for me, I’d be working on my own, but I would be working on my own doing things and doing experiments and I learnt a lot about amplifiers and particularly galvanometer amplifiers which were used a lot for very sensitive work. A galvanometer amplifier essentially is a galvanometer that you actually have a mirror that’s on the suspension of the galvanometer, of the coil that is moving, so that when you shine a light on it the light moves quite a long way. It’s obviously very slow, but it’s quite sensitive, and then you have a photocell that that light falls on that is divided into two. So you have one half that is in the opposite sense to the other half, so when the light is exactly in the middle you get no signal. The moment the light moves very slightly to one side, you’ve got a differential system coming in, so that you’ve got a very sensitive measure of the movements of the light. Of course you then have to ensure that that light is absolutely stationary, that the galvanometer is on a vibration-proof housing, that there is no vibration, that there aren’t air currents and things, it’s in a dark room and the whole thing is quite sensitive. But when I said I had nobody working for me, that’s not quite true because in the summer I would have a student who wanted laboratory experience who would come and in fact many years later Professor Stoneham at University College pointed out that his wife had actually worked for me at Teddington. She still remembers it. I was a bit worried at first, wondering how I had treated her, but he and – I didn’t meet her – years afterwards, she assured me that it had been quite a happy time and she’d learnt a lot. So you never know do you? It all comes back at you.

What do the glassblowers do? In a place like...
Well, they constructed all the equipment. I mean a lot of the work that we were doing was done in a vacuum and the glassblowers would have been making all of the vacuum systems. They would make pumps that you used, they would – not me, they didn’t do a great deal for me, but they did a great deal for George and Frank. And most laboratories required a glassblower for much of what they were doing. Certainly, you see, all the preparation of the photocells would be done in glassware that had to be prepared specially for them.

What was Walter like?

Walter was, Walter had had a grammar school education, but he’d left at sixteen I think and then started work. I can sort of let you have a written version of what Walter was like because I did his obituary for his widow, which was interesting, because she asked me to do this about two years ago before he died, on the grounds that she definitely wanted me to do it but she wasn’t sure who would die first. Well, that was sensible. I mean Walter was in his nineties, but I was well into my eighties and she definitely wanted me to do it because I was the person who’d known Walter best. In fact, I am going to digress here and change the historical side. Walter had worked for me at Teddington and then later on when we all moved to Baldock, which we’ll come to, he’d come with me and essentially was my mainstay experimentally in the group. When I had moved to Malvern he could have come with me, but for various reasons he didn’t and he stayed in Baldock. But then he retired after some years and then I went to GEC and started a group of young people there who knew nothing serious about working in a laboratory and I asked Walter if he’d like to come back out of retirement and join me. And he said yes, he was bored stiff, so he would come. So he came and worked for some years in the lab and you will find that the young people thought he was amazing. He was the kind of person when you asked how to do something, he would tell you how to do it, come after about an hour and see how you were getting on and then would say, oh for God’s sake, I’ll do it. And then he would do it, which of course they all learned to do, they knew they didn’t have to actually do it, they just had to work on it for an hour and then Walter would come along and dismiss them and carry on and do it. And he would do anything. I mean he would do vacuum stuff, he would do evaporation, he would do preparation of materials, he would do optics. He was a John Strong in person and would know it and the gallium arsenide that we did owed everything to Walter, that he would do the preparation of the material, essentially, and the purification preparation. He would do the glassblowing as well if necessary.
**What sort of, what made him a good technician?**

His interest in what he was doing. He was always a practical man, that he would do things in the house, he would do-it-yourself. If you mentioned that you were going to be laying lino in a room he would say, oh I’ll come and help you with that. Well, helping with Walter, as I say, meant that before two minutes was up he would suggest you went and got the tea ready and then he would do your lino. The way he did lino is he needed a lot of newspapers and some sellotape and he would make a paper pattern of the floor, which essentially meant that he’d be putting rolled up pieces of newspaper, flattened so they were quite rigid, and he would stick them all together with sellotape and then would lift up the whole pattern that he’d made, which essentially was an accurate map of the floor of the room. He would put that down on your sheet of lino, he would then cut round it with a sharp razorblade and now you had a lino map of the floor, and he would take this and put it in and then everyone would come and watch and he’d put it down and it would just go into place and would be exact, I mean within a millimetre. Because he was careful in how he did it. He would also do decoration and things like that. When his mother did spring cleaning she would lift up the linos in the house and vacuum clean underneath them where it had been. I never knew anybody that did spring cleaning like that, but Walter’s mother insisted on it. But Walter was the ultimate practical person. And he would obviously do gardening and everything else perfectly. But he was a real gem. And as I said at his funeral, that there are many scientists who owe their reputations to the work that Walter did to help them. Right so, we’ve got to Teddington. [59:30] I was now probably about third in the group. There was Tom Pratt was the group leader and there was Alastair Gebbie who – none of these had got their PhD, they’d all come up during the war – and there was me. And there were some others who were around but they weren’t as qualified as I was, except for George Starkiewicz and Frank Kicinski and a mathematician called Makowski. Now, as you can guess, he also was Polish. Don’t ask me why we had so many Poles, I do not know, but the group had these Poles and probably some more in it that I can’t remember. And Makowski was a mathematician. We didn’t quite know what to do with him so at one stage Tom Pratt asked if he would design a radiation slide rule. Now, definitely I’d better stop here and show you a radiation slide rule.

*I’m just thinking, is the slide rule for calculating radiation or…*

Yes.
Right, okay.

[end of Track 6]
So, radiation slide rule – what is it for?

Okay. It actually tells you, or you can see from the slide rule, every property of a hot body, which shows you what wavelengths are emitted from it, in what wavelength spectrums the radiation is and you can use it obviously for any temperature, I mean I forget what this one worked from, but it certainly worked from something that’s very cold to something that’s very hot. And you can get the answer in the amount of energy coming out or in the number of photons coming out. And this was original, what Makowski was doing. And he worked at it for some months and produced a prototype that was printed and then went to the, I think this was done before I got there. I did actually get a radiation slide rule, everyone had them, and I think that was Ted Lee was the boss still by then, he didn’t leave till about ’46 and when Makowski presented the thing to him he was very proud he’d done this and Ted said, ‘Well, okay, well give me a calculation’. He said, ‘Well, what calculation can I do?’ He said, ‘Well, calculate the radiation that falls on the earth from the sun, because that is something that’s useful, tell me what the solar constant is’. He said, ‘That is easy’ he said. So he went away and came back and said, ‘This is the answer’. And Ted said, ‘Makowski, if this is correct then we’d all be dead’. He said, ‘This is a minute amount of radiation’. And Makowski said, ‘No, cannot be, I mean everything is done, I’ve worked it all out, it must be right’. And then he said, ‘Show me your calculation’. And Ted said, ‘You have made an error’. He said, ‘I’ve made an error?’ He [Ted] said, ‘Yes, this is the biggest error you have made in the history of scientific calculations’. He [Makowski] said, ‘What error have I made?’ He [Ted] said, ‘You have left out the area of the sun in square centimetres’. He [Ted] said, ‘Why do I need to put that in?’ He said, ‘The sun is the point source out there at that distance’ he said, ‘You have to put in the area of the sun because if the sun was a point source we would all freeze, but you have to multiply your answer by the area of the sun in square centimetres’. So Makowski grumbled and went back and when he put in the area of the sun in square centimetres he got the right answer. So that was Makowski, but Makowski had left the group by 1950, but there were the three Polish gentlemen all working very hard at their own thing. As I say, one was a mathematician, Starkiewicz, George Starkiewicz, was a physicist, a scientist and Frank Kicinski was a chemist. And that is significant, as we will realise later on. But now in 1950 it was decided – well, it probably was decided in 1949 actually – that the group was an anomaly. As I’ve said, the Admiralty Research Laboratory was Admiralty research and they were mostly doing things that the Navy wanted, which was essentially ultrasonics mostly. They had another
establishment, the Admiralty Gunnery Establishment, which was down at Portland, but Admiralty Research really didn’t require infrared. But there was an establishment at Bal dock, called the Services Electronics Research Laboratory, which did have a small infrared group and by that time Malvern also had an infrared group, so it was thought that the most sensible thing would be to combine the inter-services research group, which was administered by the Admiralty, with the group at Teddington and move the people from Teddington up. And we all had to make a decision did we want to go or would we take a different job in there. Well, we had to think about it and we decided that we would move. Betty would have to change her job and they would help us in finding accommodation, but it sounded interesting. And most of the group, which was about half a dozen people I suppose, reckoned we would move up and join the infrared group which was slightly smaller, I think there were five or something up there. And they were working on an infrared imaging tube up there, so it was decided we would move up there. So, in 1950 we moved up there and we moved first of all to Stevenage and then Hitchin and then finally we were given a prefabricated home in Baldock itself. Baldock was a small, compact laboratory that was, although it was called Services Electronics Research Laboratory the people there were part of the Royal Naval Scientific Service. I mentioned earlier that there was a Royal Naval Scientific Service and by now it had become established, it had its own journal, and we were all part of it and it was run by the Admiralty and was very closely connected to an organisation called CVD. [06:15] And this we have to spend a little bit of time on. Before the war the various services – there was no Ministry of Defence then, they were all run independently – had to decide on certain responsibilities and electronics was becoming quite important to all services and it was agreed that the Admiralty would look after it for all the services and they did for the war and for a brief period afterwards. Now, the electronics had largely been radar and this had been run not by the Admiralty, but the Admiralty had been responsible for the components, including the tubes that actually generated the microwaves. And there were other components in a radar set like the crystal rectifier and various windows and wave guides, and an organisation had been set up to manage this, called the Committee for Valve Development, though there’s been dispute as to what actually the letters CVD stood for. Some said it stood for Co-ordination of Valve Development. As time went by it still was responsible for all of these devices, but then electronics changed in its character with the invention of the transistor in 1947/48 and clearly something had to be done about it and things were done about it, but the name was no longer appropriate. So the ‘D’ became Devices. So it was Committee for Valves and Devices, or something else, but it was always known as CVD. And it was a very important part of the electronics research administration in the UK because it was responsible for much of the early research funding and
for some of the device… development funding. It was in the Admiralty and the people who
manned it were in the RRNSS and they were Scientific Officers or Senior Scientific Officers.
And it organised itself through a range of committees. There was a main committee that was run
at top level by the chief of the Royal Naval Scientific Service. And then there were various
committees looking after different things like passive components, transistors… and later on, well
even then there will have been display devices which would have been tubes, imaging tubes, and
there will obviously have been some high frequency devices like magnetrons and things that were
being run through it. I didn’t have too much of a connection with it then because it did not run
the infrared, which was done through a different organisation called the Joint Infrared Committee,
because by then Malvern was doing quite a lot of work on infrared. [10:10] So now we were
moved to Baldock, which was essentially doing research on microwaves, it was a microwave tube
establishment which had been set up to follow up the work on the klystron which had been
invented by – at Bristol – by a man called Robert Sutton and at the end of the war he was asked if
he would come and join the Civil Service and run this establishment. And had decided the
establishment should be in Baldock, which had been a shadow factory – a shadow factory is a
factory that never made things, it was there in case it was wanted - and this was just off the Great
North Road, and it now became set up to make experimental microwave tubes and do research on
advanced tubes, which it did. But it had a small infrared group and don’t ask me why, but it did,
and they were doing just an imaging tube which somebody had an idea for was going to really be
a thermal imager, which was not straightforward at all. So, we moved there and Tom Pratt was
the group leader, largely because the man who was the senior person in Baldock, Jimmy Edmond,
had no ambitions for running things, he wanted to do his experiments, he was pretty certain that
he wanted to carry on and make this imaging tube. And I was there by now, I was getting on for
twenty-five, and within a very short time Alastair Gebbie decided he was going to go to Reading
and do a PhD and Tom Pratt was summoned to headquarters and I was running the infrared
group. And then I was told that one of the things that we had to do was a medium weapons sight
for the army, which essentially was an active infrared system that would go on a machine gun,
and kindly develop it. [13:05] And at twenty-five I was responsible for the infrared programme
of the country. I’d only just learnt laboratory practice, remember. I mean what the hell, I mean
the funny thing was I didn’t even query it, I didn’t say do you, I should have some training in this
or I should sort of be told by somebody how you do this, I just, I mean it just happened almost
overnight. Now on the one hand I had these two Polish gentlemen and we were now responsible
for making infrared photocells. This is what we were doing, making infrared photocells. These
were lead sulphide photocells and there were two types. One of them certainly we had inherited
from the Germans, the chemical cell. This was much easier to make and much more constant in its properties, but it had to be cooled to CO$_2$ temperature to have enough sensitivity, so you had to have a cooler system, which you could have, it wasn’t that difficult to cool to CO$_2$ temperature in glass, but it was a complication. The other cell was an evaporated cell which George Starkiewicz could make and he probably could make them better than anyone else in the world and he had made these during the war. So had other people, the Germans hadn’t made so many evaporated cells. They had done the chemical cells and the net cells that I mentioned earlier. The Americans had moved on from thalloid to lead sulphide, but we reckoned ours were the best in the world at that time. But we had also started work on lead selenide. Now, you asked earlier why we were interested in the 3.4-4 micron window and the reason for that was if you could work there you could work with cooler targets because the peak of the black body emission from a body moves to longer wavelengths as you cool it, so for a hot body you’re very easy operating in the near infrared at one micron if it’s 7 or 800 [degrees], which is okay if you’ve got a red hot poker or something. If you want to work, look at a jet plane and you can see part of the jet which is quite hot or you’ve got quite a bit of the structure, you could say for a few hundred degrees centigrade, lead sulphide and 2.7-3 microns is okay. If you now want to look either at the plume from a jet stream or from the gases, well from the gases or the body, which is much cooler, or you’re thinking about tanks where the exhaust you think will not be exposed or you think it about ships, you want to be able to detect cooler objects still and you start thinking about 3.4-4. This isn’t quite as good as working in the 8-13 micron window, which is really called the thermal window, and there you have to use, well you had to use then, non-selective materials, you would be using thermopiles which heat up bolometers of some kind, but they are much slower and you’ve seen the kind of pictures that you have from a map of something that’s scanned, and it takes much longer to do that because they are slow, but if you want to do a rapid scan you want a fast photocell which will detect photons rather than energy and here we wanted to move to the lead selenide. So, George was doing lead selenide by evaporated means, Frank was learning how to do lead selenide by chemical means, the group that had been at Baldock previously and was still there was trying to make a thermal image tube, which was based on a very thin film that they were scanning with an electron beam, and suddenly I was given this responsibility for the medium weapons sight. [18:20] Now, the medium weapons sight would need a decent image tube and I showed you the tube that was going to be made. This was being made by the English Electric Valve Company in Chelmsford under our contract and this was all done as a development contract. The actual sight, that’s the optics and the power supply… I think that was it, would be made by Barr & Stroud’s in Anniesland in Glasgow – I had no say in this, this was, not that I
would have varied it, I didn’t know anything about Anniesland or Barr & Stroud’s. I did know the people at English Electric. English Electric were going to make the image tube, which we had never made before. I mean we’d made RG tubes and suddenly I was responsible for these two contracts, I was responsible for the research going on and suddenly I realised that the lead selenide was becoming very important because Malvern had decided that we needed an infrared missile, which was going to be called Blue Sky or something or other, Blue… whatever.

Blue Jay?

Blue, no Blue Jay I think – was it Blue Jay? There was a Blue something which was a long range weapon. But this was an air-to-air weapon which was going to be the first infrared guided missile. We’d got radar guided missiles and things. And TRE very cleverly had said that we could make this missile and had used as the prototype a photocell which we had made and which they had borrowed and then suddenly they realised that they had taken on a contract to do this and what is more, that the Mullard’s people who had taken on making the photocell suddenly realised that their contractors did not know how to make the bloody photocell anyway, that it was in the hands of a totally different laboratory. So I suddenly was plunged into those politics, which I have to say more about later, but which I’d not appreciated. So this is what I was suddenly running. What I haven’t said is the two Poles hated each other and wouldn’t speak to each other. So I, I mean I was on perfectly good terms with either of them but they would not talk to each other.

What was the cause of disagreement?

Well, one was a physicist, one was a chemist, they had nothing in common, Frank was pushing his type of chemical photocell, George was sure his type of photocell would work and they had nothing in common, basically. The fact they were both Polish was probably even more of a problem than you might have thought that they would have sort of wanted to be together with each other because they were in a foreign country, no way. So, if you think that all of this was beyond me, you are quite correct, I had absolutely no idea what I was doing most of the time. Barr & Stroud’s was a very difficult organisation to work with, largely because the man was running it was very much a dictator and they had very little equipment. It was said of them that one person queried, said is it all right if I come back this evening to use the Avometer. Now, Avometer were the multi-range meter and they had apparently one, so could I come back and use
it. I was helped, I must say, by – oh, and a major, we had, the establishment had a major, his name was Frazer-Scott, and they would be doing liaison with the army which was great, but the trouble was, they only stayed for three years and for the first year they would not interfere with strategy because they said they did not understand it as yet. The second year was fine, they actually knew what was going on and could help you. The third year they refused to do anything because they didn’t want to commit the man who was coming after them and things. So you got one year out of three working with them. Later on they changed it so the things went on for longer. [23:29] Right, so I went up to Barr & Stroud’s and was greeted by Dr Strang who was the gentleman who ran it. He did run it, I mean if you rang up the person who was working on your project to find out what was happening, you’d speak to Strang, I mean the call would go straight to Strang. And you’d say, ‘Oh, can I speak to Dr So-and-So?’ ‘What about?’ ‘Well, I want to check on progress.’ And he’d say, ‘What progress?’ So he would cross-question you and if he was happy he would say, ‘Oh all right, I’ll put you through to him’. But you couldn’t talk directly to the people. I wasn’t happy with this, but anyway. So we went up and I went up with Frazer-Scott on the train, it was probably overnight, we got there and went to Anniesland and were shown into Strang’s office and we arrived just at lunchtime, and this is important, we arrived just at lunchtime. And he said, ‘Oh, we must go to lunch, we must go to lunch, it’s getting late’. So we said, ‘Yes, yes, fine’. So we turned to go into lunch and I discovered that the canteen, though it wasn’t this, it was really a dining hall, was in two halves. Well, it wasn’t in two halves, there was a dais, most of it was at a lower level, but there was a dais where there was one reasonably large table with perhaps ten people sitting on it. Strang went to sit in it and said immediately to Frazer-Scott, ‘Would you like to join me?’ And Frazer said, ‘Well, yes, yes, all right’. And he said to me, ‘And Mr Hilsum, and Hilsum, would you like to find a seat down somewhere’. I said, ‘Yeah, fine’. So I went to, found a seat, then this – I was not a Dr by then. So I had my lunch and Strang had his lunch and Frazer-Scott had his lunch and then we all got together and Frazer summoned me from the back of the hall and we went off and sat in a room and he said, ‘And Major Frazer-Scott, would you like to take the chair?’ And Frazer, horrified, he looked at him and he said, ‘Oh no, no, no, this is Hilsum’s meeting’. At which Strang got absolutely horrified, he’d realised that he had done the wrong thing. I said, ‘Yes, it’s my meeting, I’m the contractor. Frazer actually helps me’. And Strang didn’t know which way to turn, particularly since they had not made much progress and I made it clear they had not made much progress and things had to change and Strang had to get his act together otherwise this contract would be cancelled, there were plenty of people who would take on this contract. Strang was not amused, he didn’t know what to say, he was taken completely aback. I will say that he never
attended future meetings, which suited me down to the ground because basically he just was a complete control freak. They did all right after that, but I mean it was okay. Now, the main problem was actually not Barr & Stroud’s, it was that damn image converter, because I mentioned caesium earlier, the problems of evaporating caesium. There was a very nice lad, Rupert Stowe, at EEV, whose job it was to make the tube. And they could make the tube but they couldn’t make it live, that it would give us good performance but really after a day or two it just would die. I suspect that the cleanliness just wasn’t good enough, that it wasn’t baked out well enough and wasn’t clean and it would not last. So we used to have trials of this and when we had a trial, the trial of this equipment is not a small thing. You have to set it up with the army and as often as not there’ll be a general or two wanting to attend, but of course we would have a rehearsal the night before and they would have army people sort of around firing blanks and things to see what would happen with this system and we had the experimental tubes. And Rupert would bring the tubes down and he would make them in the morning and bring them down, but the problem was, as often as not it would start raining and the generals wouldn’t come out in the rain. So they would say, okay, we’ll postpone it for one night, we will have it tomorrow, or we will have it in two days’ time, at which a horrified look would come over Rupert’s face because he would know that his tubes wouldn’t be living by then. So he would have to hare back to Chelmsford and make some more tubes in the hope they – it was ludicrous, it really was ludicrous. So this whole thing was falling further and further behind and eventually, when somebody pointed out to me that we were now running behind the Norwegian Navy in our ability to make systems, I said enough is enough, the responsibility must pass elsewhere, the army must look after their own. And I knew the people down at Christchurch, the SRDE – Signals Research and Development Establishment – and they had a man there, quite a senior person with a good sense of humour and he said he would take it over because he wouldn’t be strained at all by this responsibility. So Rupert went off to Bermuda, I don’t know what happened to him. I think he, he became quite prosperous I think. EEV was quite happy because they were making shadow masks, colour tubes and the sole licensee in Britain for RCA, which we will come back to, after many years. So they were reasonably happy. I’m not quite sure who made the things, I should say that there was a complication actually. The reason why EEV had taken on the responsibility for making this tube was there was a gentleman called Karl? Karl Frank, who had made tubes in Germany during the war and reckoned that he knew how to make the tubes, but somehow the English environment didn’t suit enough, even though he claimed that as Rupert said, his tubes just don’t live. So he went back to Germany and started his own company
which probably was all right, and in the end – I’m not even sure that that medium weapons sight finally survived, but I had had enough. Go on.

[30:50]
*I was just thinking, I was wondering – I’m going to have to stop this in a moment because the card’s nearly full and it’s getting on – but I was wondering, before dropping you in that situation did the Civil Service give you any sort of management training?*

No, no, no. No. Tom Pratt came along just one morning and said, ‘Oh Cyril, interesting development’. I said, ‘Yeah?’ He said, ‘I’ve got a job in headquarters which I have to go to at the end of the week and you’ll be looking after things’. I said, ‘What?’ He said, ‘Well, Alastair’s gone off to Reading’ he said, ‘George’ – who was George Starkiewicz – ‘can’t run things’, he said, ‘and Jimmy Edmond doesn’t want to. So I’m afraid it’s up to you. Anything, any help I can give?’ I said, ‘Prayer’. I mean, what was there to do? I mean there was no alternative. No, the idea that anyone should train anyone in those days, no.

*Did the fact you were only twenty-five on taking on this responsibility cause any credibility problems with your young age?*

Oh yeah, caused a lot of credibility problems, yeah of course. Well, I’ve told you about the credibility problem with Strang. It caused no credibility problems locally, people were quite happy, they’d got to know me. There were no, absolutely no problems in the group. George and Frank were quite happy as long as they reported to me and not to each other. Jimmy was happy, even though later on things changed and he was put in a difficult position, but it wasn’t anything to do with – well it was something to do with me – but it wasn’t going to cause any friction between us, we will come to that. But he really wanted to do his thermal image tube, he didn’t want to run George and Frank and Barr & Stroud’s and English Electric, who would? [32:50] Yeah. No. But now we got into really serious political problems. The Barr & Stroud’s was local and that was okay and nobody really worried that we could take care of that. But the infrared tube, the infrared photocell, that was a problem. And I may have caused some of that problem, as was pointed out to me later. Right. TRE Malvern had taken on the responsibility for this infrared missile and they were perfectly capable of making the missile, but what they weren’t capable of making was the photocell that was the heart of the missile, then. And this was clearly going to be made a lead cell and this wasn’t going to be the first infrared missile, the Americans were making
Sidewinder, which had been made in a strange way because that proved to be a very successful missile but was made entirely without permission. It was a group of scientists decided that infrared was good enough, they could make a missile, and they made it in their spare time with petty cash and various ways and of course once they made it and it worked everybody said, well it was them, I mean they had done it. So they did it. Ours was done as a proper project, but Malvern had taken on this responsibility and when they went to Mullard’s and Mullard’s had agreed they would make the photocells, Mullard’s said, ‘Well how do we make the photocells?’ And they said, ‘Oh, we’ll get the recipe from Baldock’. Well, they came to me and they said, ‘Can we have the recipe?’ I said, ‘What do you mean, the recipe?’ And they said, ‘Well, you gave us a photocell, how do we make it?’ I said, ‘George makes them’. They said, ‘Well how does George make them?’ I said, ‘You can come and see how George makes them’. Anyway, Mullard’s came and Malvern said, ‘Well, you’ll have to teach us how to make them’. I said, ‘But that’s ridiculous. What’s the point of teaching you how to make them and then you teach Mullard’s how to make them? It would be much more sensible if you gave us the contract so that we can then teach Mullard’s how to make them.’ Mullard’s said ‘yes, this is the sensible thing for us to do.’ Malvern wasn’t willing to do that. Politically they were not willing to do that. And that’s when I ran into trouble because the man who was responsible at Malvern was Robin Smith, the head of physics, who was a very senior person. He was in his fifties, I would think, maybe late forties, and he couldn’t understand this, thought I was just being obstructive, which I was. But I didn’t see that I should actually let my own people down. I mean George had done all the work in developing this photocell, why should the credit for it be taken away from him? We then got involved with de Havilland’s who were doing the actual missile, I mean they were going to be making it down at Hatfield. George Hough came to see me. All of the people who were really involved in it, like Hough and the people – forget who it was, I can remember what he looked like – at Mullard’s, they wanted to work with us, basically, and what was happening was that they were coming to us, we were making their photocells and they were not telling Malvern that they were getting the photocells from us. Malvern thought they were making them and learning how to make them. Well, so they were learning how to make them, but I wasn’t going to stop the development of the thing, but damned if I was going to teach Malvern how to make things and then they would take all the credit and George would be left out in the cold. So this didn’t go down well with Robin Smith and it didn’t go down too well either with the chief of the Royal Naval Scientific Service, my boss’s boss’s boss, who was Sir William Cook and he went on record saying that I was the only person that he could not sit on a committee with. I was now twenty-six. Yeah. Ah well. [37:30] So, my own people weren’t backing me. Sutton was
backing me, he could see what I was doing and he said that what I was doing was right, but he wasn’t prepared to intervene and sort of take my place on the committee. There was a Joint Infrared Committee at which I would sit and basically object to what Robin Smith wanted to do. Fortunately, Robin Smith had a sidekick called Frank Jones, who was the inventor of Oboe, and he proved to be a very good friend and essentially he would act as an intermediary between me and Robin. What Cook did was to set up a subcommittee which would look after this missile and which I would be on and Malvern had three people on it, Robin Smith chairing it, but Frank Jones was on. I’m not sure what Frank was responsible for. But Sid Jones, who was actually doing the design of the missile, he was doing the research for the missile, and we got on like a house on fire. I mean we both knew that we were trying to make a missile, that was all right. Robin was trying to make a name for Malvern, I think. I may be doing him an injustice, but anyway, he was very political. Frank was trying to keep the peace between us, which he managed to do quite well. So the missile made a lot of progress and we learnt how to make the cells, Mullard, they had a much better design for the cells than George had. It did need some cooling, it worked better with some cooling, and they redesigned that. I helped actually in the system because Sid said we’re getting real problems here from interference from clouds and things and I’ve, we’ve got over much of the problem by having a retina, a reticule in front of the retina which is a black and white pattern. Now, the missile works by a chopper chopping the radiation, because you want the radiation, you want the signal to be AC not DC, because you can amplify it much more easily if it’s alternating, direct current amplifiers are much more difficult, you get drift. You can do it but it’s more difficult. If you can convert the signal into a signal of a definite frequency you can make a selective amplifier and that gives you much more sensitivity. So what they had done is they had made a chequerboard chopper so that although it would modulate a point source, which an aircraft engine would be at that distance, modulate a point source, if there was a line like a cloud, then it would be, it wouldn’t be chopped. I mean it crosses too many elements. And he said the problem is, and he wrote to me and said I’ve still got this problem that I get too much interference from the cloud particularly when the sun is on it, that the sunlight is too strong. So I wrote back and said, why does the chopper have to be black and white, why can’t it be two colours so that the transmission, you can have the transmission through the darker bit at one wavelength and the transmission through the lighter bit at another wavelength. And you balance those two transmissions so that for a very hot object they cancel each other, but for a colder object they won’t. So you would discriminate, not only on the shape, which you’re doing, but on the colour. And that was called a two-colour chopper, and it worked. And that was used and he was very grateful to me for that, and that was all right, I mean it was all, we were all… that’s the
really irritating thing, that we were all working together on this thing and making progress, but over all of it was this rivalry between Baldock and Malvern. Anyway, we then had another thing that came up. The Navy wanted us to detect submarines. This all came about because there was a gentleman – well, first of all I should say that we obviously had a problem in detecting submarines. We detected submarines normally by their noise and had taken that to a certain stage, but as always happens with measures and countermeasures and things, people were making submarines quieter. Also they were being submerged for longer, they could make a very quiet submarine, but it needed to snorkel now and again, so it would stick its snorkel pipe out but when it was submerged it would be very quiet. And obviously the Americans had the same problem. But then one of the people at the Naval Research Laboratory in Washington DC said that you could detect a submarine by the thermal wake that it leaves behind it. Now, this was a very interesting suggestion and what he had done, he had got a blimp and he had used some of that equipment, you saw that equipment, type of equipment that was used during the war, I showed you in that book, which was a scanned thermopile, effectively, and he had used this to scan the surface of the sea and had shown that you got a line pattern of in general colder water for some miles behind a submarine. Now this was very interesting if it was correct because it meant that not only were you detecting, not only could you detect the submarine, but you could detect it from a long way behind it, which meant that you could go over sea and pick up the wake and then follow the wake to find out where the submarine was. We certainly had ideas that you could detect the snorkel of a submarine by its infrared signal, but that is like seeing the thing and you’ve got to be there to see it. If you can actually get a track behind it, then that would be much better, but you had to admit when you looked at the patterns that Harry, Harry Clark was showing us, he would say, well that’s a submarine. And you’d say, yes Harry, but what’s that? He said, ‘Oh that’s noise’. ‘Well, how do you know that’s noise and that’s the submarine?’ ‘Well, you can tell, it’s a different shape.’ ‘Doesn’t look a different shape.’ ‘It’s a different shape, I can tell.’ And he could. There’s no question that he seemed able to read these patterns and do this. But it was reckoned that we ought to do this, we ought to do this. So who was going to do it? Well, who the hell was there to do it? Yeah, yeah. So, this was the early 1950s, I suppose ’52, ’53. I could be wrong, could be ’54. But this one was thrown at us and we worked out that what we needed to do was to make essentially a radiometer that would look at the surface of the sea, that we would do trials with submarines and with ships, because you get a wake from a ship, and we would have a radiometer that looked at the surface because this is the way it would have to be done in the end, and we would also have an array of temperature detectors that would be towed in front of the ship. It obviously couldn’t be behind the ship because the ship would be interfering
with the thing. The general concept was that the submarine was stirring up water from the depths as it went along, not just from its propeller, but partly from its propeller, but also from its body, that it would be doing this and if so there was almost nothing that could be done as a countermeasure. But our measurement had to be done in front of the ship so we would make a bowsprit that stuck out in front of the boat and we would have our own radiometer which was a tube, that was probably about six to eight feet long, about one foot wide that had a mirror in it and a detector focussed on the mirror, and amplifiers. And also we would have towed from the bowsprit well in front of the ship underneath the sea an array of thermocouples that then would also come back and be measuring the temperature, so we’d measure the profile of the ship. And we knew that we then had what was the National Institute of Oceanography was part of the Royal Naval Scientific Service under a man called Henry Charnock, who was again a very nice person, and they would be responsible for the measurement of temperature, we would be responsible for the radiometer and Malvern agreed that occasionally they would fly over the whole area that we were looking at with a cooled lead telluride detector that they had made. They had developed lead telluride photocells which they’d hoped were going to be useful in the missile originally but which had been decided was no good because it needed liquid nitrogen cooling and there was no way at that time that they thought they could do that. Later on they reckoned they could, but at this time they couldn’t use Yellow Duckling. But Yellow Duckling could be used as a surveillance system, so we were going to do this, so we were going to do this. So we built our bit and Henry Charnock built their bit and we were given the last coal burning trawler in the Navy, the Tiree. Well, anything, you must have heard the sailing ship Venus, there is a rude limerick about Venus, Tiree was as near as it gets to that. It was given to us before it was being thrown on the scrapheap and it was a very surreal experience working with them. Well, we set out first of all to measure at Portland. I am not a good sailor, but it’s been my fate to be responsible for groups which I am not competent to lead, and we went to sea and before long I was curled up by the funnel of the ship with a duffel coat thrown over me. There were one or two others by my side, but as far as I was concerned I was there. Henry Charnock comes along, he was deputy to me on the trials, and said, ‘Cyril, it’s a bit rough’. I said, ‘Yes Henry, I know that’. And he said, ‘The captain says that it might be too rough for us to go out further and do the trial because it could risk the bowsprit out there, but on the other hand we could go back to harbour and try again. What do you think we should do?’ I said, ‘Henry, in my condition that is not a fair question to ask me. You have to make the decision’. Henry decided we should stay out, and we did detect the wake of our own boat. I mean we didn’t have a submarine but we could just go round in a circle and make your own wake. And everything worked perfectly, that was fine, except me, I
wasn’t working perfectly. [51:35] But now we were due to go to Malta. So that was all right, we
got all the equipment ready, we were going to be hosted by HMS Tyne which was in Malta,
everything was ready, we were going down and of course Walter was a key feature in all this. He
had designed a lot of the equipment and constructed quite a lot of it. So he was going to go down
a week before me and I would then follow and I think one or two others, and Henry was going to
come down quite separately. So Walter sets off with the radiometer - remember I said it was
about eight foot long and about one foot wide - and all of the equipment. He was going to Luton
Airport. He rings me, he said, ‘Cyril, I’ve got a problem’. I said, ‘What’s the problem Walter?’
He said, ‘Well I’m here and everything’ he said, ‘most of the equipment’s okay, they’re quite
willing to take it, but the captain of the aircraft said there’s no way he can take the radiometer.
We thought it would go in the gangway but he says you can’t go in the gangway, it affects the
safety. It can’t go in the hold, it’s too big, it’s got to go by freight’. And I said, ‘By freight’ I
said, ‘but that’ll take a week’. He said, ‘Yes’. I said, ‘Oh Walter, all right. Well, load it up for
freight and you come back here and we’ll go in a week’s time’. He said, ‘What did you say
Cyril?’ I said, ‘Come back and we’ll go in a week’s time and send the thing off’. He said, ‘This
line’s gone very bad, I can’t hear what you’re saying’. I said, ‘Walter, don’t do this to me’. He
said, ‘Oh, it’s a terrible line, I really can’t hear what you’re saying, but okay, I’ll see you in a
week’s time and we can talk about it then, cheerio. They’re calling for the plane now’. He said,
‘I can use my time there’. I said, ‘I bet you can use your time there’. And that was Walter. Bad
line! I should have said that he’d been in the army. Walter knew all the tricks. He also knew
about losing things overboard. If you lose something overboard in the Navy there’s no
comeback, I mean it’s lost overboard, that’s it, so kit gets collected. But we went down and did
our trials in the end, I mean yes, it all worked, but essentially we proved that you could detect a
submarine some distance behind provided that some part of it was cutting the surface. In other
words you definitely could do a snorkelling submarine, which was useful, and all of this is quite
well known. But we could get no certain detection of a completely submerged submarine. Yes,
there were some signs but you couldn’t actually do this. Harry Clark might be able to, but we
couldn’t. But it would depend on the noise level that you had in the particular sea that you were
there. Under some circumstances if the number of natural wakes was very small you might be
able to do it, but to check on whether it was a valid system we would have to do surveys around
the main waters which we were concerned with. So, we had our meeting of the Joint Infrared
Committee with Sir William Cook presiding and the director – no – the deputy director of
physical research, Smith, Henry Smith there and I made my report and Cook said, ‘Well that’s all
okay, satisfactory I suppose, but you’re going to do this survey, how long will it take to do it?’ I
said, ‘Well, to do these seas that people have said are the important ones, it will take about three years’. He said, ‘Three years?’ I said, ‘Well, yes. There’s a lot of water we’ve got to cover, it’ll take three years’. He said, ‘Well, that’s too long’. He said, ‘How long would it take you if you had three ships?’ I said, ‘We haven’t got three ships, there aren’t three ships’. He said, ‘How long would it take you with three ships?’ I said, ‘We haven’t got the amplifiers’, I said, ‘They’re amplifiers we’ve got from the States, I mean we haven’t got the equipment. He said, ‘That’s not what I’m asking you. I’m asking you if you had three ships and three sets of equipment, would you be able to do it in one year?’ I said, ‘If you’re asking me if dividing three by three is one, yes, that is the answer’. He said, ‘Right’, he said to Smith, ‘See to it, will you?’ Well, I got back to the lab and Sutton called me in the next morning. He said, ‘What the hell went on yesterday?’ I said, ‘Cook went mad’, he said, ‘he’s furious with you’. I said, ‘Look, we haven’t got three ships, we’re lucky to have one ship’, I said, ‘it was ridiculous what he was saying’. And he said, ‘Well’, he said, ‘you don’t seem to have handled it terribly well’. I hadn’t handled it terribly well. [57:35] Cook went on record as saying not only wouldn’t I get promoted that year, but I couldn’t be put up for promotion the next year. Right, I was twenty-six, now I could have expected with what I had done to be promoted at twenty-six, what he’d done was stop me being promoted at twenty-seven. By twenty-eight it was going to get very difficult. If I didn’t get promoted at twenty-eight I was going to leave. Actually it wasn’t all that bad because in fact my – I did get promoted at twenty-eight and we’ll come to that, and in fact I got my next promotion so quickly afterwards that I’d more or less gained everything. It is a by-product and I will break into the history here by saying, many, many years later I was a Fellow of the Royal Society and so was Cook and I was coming, going into Carlton House Terrace as he was coming out and I looked at him and he looked at me and I said, ‘Do you remember me, Sir William?’ He looked at me, narrowed his eyes and said, ‘Hilsum, I could never forget you’. I said, ‘Have you forgiven me?’ And he said, ‘Hm, by now probably yes’. That was it.

[end of Track 7]
Do you want to ask your questions first?

Yeah, there were a few sort of clarification questions I wanted to ask from last time. The first was, who was Sutton who you mentioned a few times?

I did mention him. He was the inventor of the klystron at the Bristol University which was taken over as part of the Admiralty Research during the war. And he improved the klystron, which essentially was the system by which, well the vacuum tube, by which you could have radar working at higher frequencies. There was always a demand for higher frequencies in radar, partly because you wanted to be ahead of the enemy so they wouldn’t be able to detect and frustrate what you were doing, and because it gave you better resolution. So there was a need for a higher frequency tube than the magnetron and Sutton invented this tube and then after the war he was asked to set up an establishment which would really do the research and the early development of microwave tubes for defence. And it was an establishment that did take things beyond research; it had a huge collection of lathes and things where people would be working on actually making enough devices to satisfy defence requirements because then quite often you weren’t interested in large orders. You might be doing things for pilot production or the actual need for systems, particularly large systems might be limited. So industry would not be that interested in making them, but the establishment which was called SERL, remember, Services Electronics Research Laboratory, specialised in that. The infrared group was an anomaly, I was never sure why it was there, and certainly when we came we found that we were strangers to the natural progress of the lab. We were made very welcome of course, I’m not saying that, but the kind of work we did was very different and it became even more different later on. But we’ll come to that. But Sutton was the director. He had unique views on how laboratories should be run. One of the things that he was insistent on was that he didn’t want organisational positions. The Civil Service worked on the basis that people could work their way up to a career grade, and then there were positions, essentially they became people like Senior Principal Scientific Officers, and that would be a position where a person was responsible for a hundred people or so, and that was a position which gave Sutton very little control. He couldn’t get rid of the person if he wanted to, which he quite often did, as we’ll come to later, but he was much happier with the other system in the Civil Service which was the special merit promotion system, by which people could make their way up in the hierarchy while maintaining their connection with research, they were called individual
merit. And later on it became very popular with people to seek that way of getting promotion. And later on you will find that I had quite a responsibility in that as well as taking advantage of it myself in the way I progressed. But Sutton managed to divide his establishment into groups, each of which was headed by an individual special merit person, which was very unusual.

*What sort of chap was he to actually meet?*

We’ll come to that later I think in some detail. He had some unusual talents in that he would, not take advantage of his position when he was talking to people, he would talk to people, he would get involved in things. He was excellent on the things he knew, he wasn’t so good on the things that weren’t part of his own repertoire. He taught me that you never answer a question in the Civil Service until you find out why the question has been asked, because the answer will depend on the use that the person questioning you will make of your answer. And I’ve always remembered that and have told my own people it, that it is useful to know, and it is not uncommon that when someone asks a question somebody who Sutton’s trained will say, why do you ask that question, before they answer it.

[05:40]

*Could you give me perhaps an example of this or a situation from your early career?*

They’ll come up later almost automatically, but they certainly figure when, curiously enough, though I was a bit of a renegade in the Civil Service, they were quite pleased in having a renegade. For instance, I was chosen when I was sort of halfway up when I was a Deputy Chief Scientific Officer, to actually write a thing on joining the Civil Service, on the advantages of being in the Civil Service, and there was a booklet published with a picture of me in quite prominence and it started off, my article I still remember, ‘I never think of myself as being a civil servant.’ Which I didn’t, I was a scientist employed by the government. I never thought of myself as being a servant, certainly never as being civil, nobody would have ever accepted that. So yes, I was a renegade in that sense but they didn’t seem to mind. They tolerated it because I was productive, but of course it meant that I had to be productive. I can’t believe they would have put up with me if I hadn’t been getting results.

*I think my other question I had for you was, we talked quite a lot last time about some of the scientific aspects of your work at SERL and before that at the Admiralty Research Laboratories at*
That’s a difficult question to answer because it thrusts me into memories which I don’t actually have. I can’t remember, for instance, ever dealing with budgets, which I ought to have done, so somebody must have done it and shown me it and I will have said yes. I obviously had to deal with the personnel problems and people were very happy if I dealt with the personnel problems of some of our team. It can’t have been that easy, but essentially I think I was very naïve and I probably didn’t appreciate the problems that I was being faced with by not recognising them as problems. I just would go straightforwardly into a problem. Now you would say, well you were twenty-six and you were dealing with scientists of considerable reputation who were in their forties, if not fifties, and also younger scientists coming in, recruited, who would be in their twenties, what problems did you face? And I would look at you and say none, I don’t remember any. Now, that doesn’t mean to say they weren’t there, it’s that I didn’t recognise them. I have mentioned the problem other people had with me, partly because I didn’t recognise that there were problems, I would just go straight for a goal. I wouldn’t now, I have learned, I did learn, but it took me some time and [09:25] as is obvious, I did cause some problems with other people and I will say I was shielded by certain people. Sutton shielded me from Cook, which was good, Frank Jones shielded me from Robin Smith and I don’t know… I was very grateful to Frank, I always was friendly with Frank and that will come out later when we deal with the Rank Prize Funds. I got on very well with him and he was a man of considerable talent and in fact I was very happy later on to join in writing his memoir when he died, he was a Fellow of the Royal Society and I joined George MacFarlane, whose name will also come up later, in writing his memoir and I was very fond of Frank. I recognised some of the talents of Robert Sutton, but later on that all went wrong and we’ll talk about that because it is important. Robin, I always, Robin got closer to me later on, Robin Smith. I never felt a great deal of sympathy with him. I think that what he had done over the missile and the lead sulphide cells was unnecessary. But he obviously had his own agenda that he wanted Malvern to be a practical establishment. I think it’s pertinent to say that Sutton was not terribly interested in fundamental studies. He was interested in products that could be made that he could point to and we may get round to talking about one of those later on, which I thought was trivial but which he thought was important. He was very anxious that the establishment should be distinct and should make things which you can argue is very defensible. Robin Smith was much more far-sighted in that he was quite interested in,
particularly his physics group which he was responsible for, should have an international reputation for fundamentals and it did actually figure quite largely in solid state physics early on with people like Alan Gibson who became an FRS – Robin of course was an FRS. So you can see that they had different agendas. Now, when Robin was suddenly plunged into development it didn’t come naturally to him, that he saw it I think as a way of broadening the impact of the physics group rather than him being single-minded about the development. Robert Sutton would never have done that, he would have being going straight for the actual device that was made, which is in a sense why he supported me in what I was doing when I mentioned it earlier on, in protecting the expertise of George Starkiewicz and ensuring that George got credit for it. I have to say that I may have got slightly mixed up with the actual timescale of what was doing, what we were doing, that essentially by the time we came to Ballock, to SERL, the group and George Starkiewicz was more interested in progressing from lead sulphide to lead selenide. He thought it was the natural development and to some extent that fitted in with the transmission work that we had done at Teddington, which I mentioned, where we had shown that the 3.4-4 micron window was transparent. Now lead sulphides, spectral sensitivity stops at about 2.7 microns, whereas lead selenide, being a heavier atom, goes further into the infrared. So George could see that lead selenide was going to go further into the infrared and the significance of that is that it meant that you would be able to detect cooler bodies, that you could go further into the infrared where a cooler body emits more radiation. So what we were doing was quite far-sighted but now we were called on to actually help in the development of lead sulphide cells and this I have covered in the discussions that we had with George Hough and with the people at Mullard’s. And that all progressed pretty well, that the relationships were there. I think that Robin Smith was not thrilled with what was going on and I suspect that he wasn’t kept fully informed about what was going on.

[14:54]

*How did the missile story actually come to an end? You sort of talked about some of the difficulties involved, the…*

It was made and it was used, it was a good missile. It wasn’t used as much as Sidewinder was used because we weren’t involved in wars in the same way. Sidewinder was used in Vietnam quite a lot and later on there were further developments of infrared missiles, but it was much more a question of us being equipped with missiles than actually using them a lot. But there is a history behind this and we will get on quite soon to [15:35] the next development, but first I
should talk about what I was doing. At the same time I was responsible for the group and the near infrared sight being made at Barr & Stroud which we have dealt with. In parallel with that I had the responsibility, though not the practical involvement, of a thermal imaging tube because that was existing at Baldock before we got there. But there was a group of three people, a man called Jimmy Edmond, another one, Bob King, and a lab assistant, Eric Francis, who were working on a thermal imager tube, one of the first – but I should say that there were a fair number of attempts being made in America and Germany to make a thermal imaging system which would detect hot bodies, but bodies as cool as bodies, the temperature would actually pick up people.

Now of course, this is common practice now, but we’re talking about the 1945 onwards, 1950s and this tube that Jimmy Edmond and Bob King were making was an electron tube, rather like a television tube, in the sense that it had an electron beam coming from a cathode that would be scanning across the surface, but that surface here would be glass, a very thin, very thin layer of glass that actually developed the charge on its surface that was due to the thermal radiation falling on it, and it would be thermally sensitive, so it’s changing its properties and you could make it change in its properties and develop a temperature pattern, partly because glass absorbs, but largely because there was a metal film deposited on it. Now the problem with actually getting a thermal image, a heat image on the surface is that the heat leaks away sideways. The heat will leak away in all directions, I mean any hot body will radiate heat in all directions and that we could see was there and there is good physics involved in how you calculate what is going on.

But the bigger nuisance was the heat that leaked away sideways. Imagine that you were trying to get a picture of an electric fire with different bars on it. What you want to see is parts of your retina, your glass film, where the temperature is slightly higher than it is in the places where you haven’t got a hot bit of the fire imaged. Unfortunately, the heat spreads sideways and it spread sideways so much that if you have two bars that are perhaps a centimetre apart and you image those by using an optical system that might be a lens but more usually will be a mirror system, then the pattern has almost completely disappeared. And the problem can be shown by an example, that glass is thought to be a very poor thermal conductor. A piece of glass, if you put a hot object on the other side takes you quite some time before you can feel it on this side. And the heat spread will always be greater with a thicker object. Well that’s obvious because there’s just more material taking the heat away. So take a piece of glass, this poor thermal conductor, make it a micron thick, which is pretty damn thin, and you cannot get a pattern of more than a few bars in a centimetre. Now that’s a very crude picture. So you’ve got that to cope with, that even if you do the detection, are you going to make a recognisable image. The answer is that you have to make your film even thinner. Now, it’s got to be self-supporting, you can’t put it on anything
because that’s going to spread the heat. So this is the problem that Jimmy and Bob were facing, as to how did they get a recognisable picture, and they did some good physics on this, on working out what was necessary. And there was also the question of how did you absorb the radiation. The amount of radiation you can absorb is exponentially proportional to the thickness. So you want the layer to be thick to absorb the radiation, you want it to be thin to stop the heat spread. Have your cake and eat it. Well, what you do is you make the glass very thin, but then you put on it a layer to do the absorption and that layer is generally thought to be a metal. [21:30] And this was more or less where I came in, looking at this and saying that well, we ought to do some physics on this, and I started to do some physics on really what made a thermal imager tick. And that was the kind of thing I liked to do, to actually understand how things worked. And this was trying to work out, how does this thing work. And I realised that there was a pretty good theory in absorption in metal films, it was done by a man called – two men – called Hadley and Dennison, who had worked out how thermal radiation was absorbed in metal films. The reason why they chose infrared was because the physics of metals becomes easier as you work along wavelengths, at short wavelengths you get absorptions and things that complicate it, but it’s, the physics is fairly straightforward when you take a thin metal film. And they showed that the maximum absorption you could get in a thin film of metal was fifty per cent. This wasn’t great, I mean you lost a factor of two. And it works out that if you take the right thickness, which actually works out as a resistivity of 277 ohms per square, that you’ll absorb fifty per cent because you get twenty-five per cent reflection and twenty-five per cent transmission, it’s a thin film. Whichever of these things, if you go thicker you’re either going to put up the reflection and reduce the transmission, the absorption will drop, or the other way round. And I thought about this and thought well, that’s all very well but we haven’t actually got a thin metal film on its own, what does the glass do. So I did a calculation of what happens if you have an insulator, which is what the glass was, on a thin film of metal. And I discovered some strange things, I discovered first of all that the properties depend on the side that you’re looking at, which seemed to me to be against physics because I thought light went through things and it didn’t matter what direction, well it does. And then I realised that I was dealing with a fundamental problem, which is what you could call a dielectric-metal combination and so forget about the fact that it’s glass, what you have is a material that has zero conductivity and a dielectric constant or a refractive index. And I could show that if you had the right thickness of a dielectric on a metal you could increase the absorption, which was naturally interesting, it was interesting scientifically, it was interesting practically because it meant we could increase the sensitivity theory. It depended on the thickness and it was a bit like the way in which you made anti-reflection coatings on essentially
spectacles or any bit of glass, you matched the refractive index. So it was similar but not the same. But essentially it meant that if the radiation fell first on the dielectric side, in this case the glass side, the absorption was higher, but as a result the absorption was lower on the other side. Now that was doubly interesting, because now when I started looking at the actual radiation balance of the system, I realised that what I was dealing with was an isolated, or something that could be isolated because it was in a vacuum, so there’d be no convection currents, I was dealing with something settled to a temperature by the radiation, assuming I could cut out the heat spread to the side, that the only way in which it lost radiation was by the radiative transfer that you get when any body is hotter than its surroundings, and obviously if we were putting a radiation pattern on the film in the areas where it was focussed, it would be hotter than the surroundings. So what we wanted was to cut down the radiation going there. So although you are taught that absorption and emission go hand in hand, that if you make a body that’s got high absorption, it’s going to have high emission as well, in my case we got away from that, that you would actually have low emission in the areas that were away from the mirror system and this meant that if you chose the thickness correctly, you had an ideal system for getting full benefit from the radiation falling on it. I had to complicate it by seeing how it all varied with the angle of incidence, because the original Hadley and Dennison theory simply did it at normal incidence, but it wasn’t too difficult to both put the dielectric in and also put in the angle. And I could show that if you designed it properly you could match your retina to the mirror system and have it more or less isolated from the rest of the world, which was exactly what you wanted. Well, this got me quite interested in the physics generally of image converters while Jimmy and Bob were working, actually trying to make their thing work. So I started looking at other things and then I was helped because another member of the group came out with a very good idea for an image converter which didn’t involve an electron tube. And this exploited the fact that all semiconductors show a wavelength at which they change from being an absorber to being a transmitter and this is connected with the fact that there are two basic energy levels for electrons in semiconductors and they are separated by what we call the energy gap and you can excite electrons from the bottom level to the top level. And if your radiation is actually at a long wavelength there won’t be sufficient energy in the photons to drive the electrons up between those two levels. And if there is a shorter wavelength, which depends obviously on the semiconductor and its energy gap, there is sufficient energy in the photons to do this and you can excite the electrons. And essentially it is thought of for a detector, that if you want to detect radiation you match the energy gap of the semiconductor of the radiation you want to detect. But here we were looking at something slightly different, that if you looked at the absorption
spectrum of the semiconductor as you went from short wavelengths to long ones, you would get no transmission at short wavelengths, and then as you went to longer wavelengths you get full transmission, remembering that of course the energy of the photons get less as the wavelength gets longer. Now, all semiconductors show this but they don’t all show it to the same steepness, which we’ll mention later again in more detail, but also the details of how it happens became significant. Because the temperature effect of that absorption, which you call an absorption edge, because it looks like an edge or a cliff if you plot the spectrum, the temperature dependence varies considerably with different materials. Now again, there’s a lot of physics that can come in here as to why and how, what controls it. But the interesting thing was to us that it varies with temperature and now if you take a material that, shall we say, is transparent through much of the visible spectrum and not entirely, a material like sulphur which shows yellow, sulphur is yellow because its absorption edge is in the yellow. Selenium, a sister element to sulphur, is in the red, it’s got a smaller energy gap so it goes a longer wavelength. If you take a piece of selenium, preferably a thin film of it, you will find that if you look at it through sodium light, which is just in the yellowish red, that what you see, the intensity of what you see depends on the temperature, because the edge moves with temperature. So if you now can make a thin film of selenium, put it at the focus of a mirror, put a thermal pattern on it and look at it just with sodium light, the hot bits look dark. So you’d made a thermal imager and this is a very simple thermal imager; it’s only a piece of selenium and a sodium lamp. It isn’t anything like the tubes that people were trying to make. Unfortunately, it doesn’t have the same sensitivity, but it [32:18] is a very good vehicle for studying what is happening in thermal imagers. So I now could start from the beginning and say well, I have a hot object, I now want to see an image of it, what is the physics of the process. Well, the first thing you have to do is to think about, how does the radiation get to your instrument, which of course brings in the atmospheric transmission. But I knew that because we’d done all that. The next thing is I’ve now got to look at the radiation balance, but I was doing that wasn’t I, with my thin films and my dielectric. The next thing is I’ve got to see a pattern, so I’ve now got to say well, what’s the material I’m going to use, and I’m going to use the absorption edge as a, essentially as a test vehicle and see what we can do with that, so that means I need to go into the physics of absorption edges. What controls an absorption edge? There’s some quite good physics in that in different materials, and in fact it turns out that amorphous selenium is a very good material. Its edge moves much more, it’s not as steep as some semiconductors, but it’s more temperature sensitive than most, so when you multiply the two things together, the slope and the movement, you find that it’s one of the best materials to make. There are others: arsenic trisulphide, arsenic triselenide, and various things are also pretty
good. But you’ve now got this problem of the heat spread so you’ve got to make it as a thin film and this was when my colleague, Walter Harding, came in so usefully because he developed a technology for making self-supporting thin films of selenium, and since selenium is one order of magnitude less in thermal conductivity than glass, if we could make a self-supporting film of selenium one micron thick we would get much better resolution than Jimmy and Bob were able to get with their glass. So we started doing that. And it’s very simple to make a thin film, the way Walter developed it, essentially what you do is you evaporate some selenium on a piece of glass and you’ve done this having carefully rubbed the glass with soap before you started or detergent, and then you wipe it all off and you wipe it all off again and then you immerse this piece of glass that’s got the selenium on at an angle in a cylinder and you put water in, and as the water rises up it dissolves the detergent layer though you think you’ve wiped it all off you haven’t quite, so it dissolves the detergent that’s underneath the selenium and if you know what you’re doing, before long you have a film of selenium floating on the surface of your water. It isn’t tap water, it’s distilled water so that you’re not bothered with odd bits of crud around. And then you pick it up on a glass ring.

Sorry?

An annulus. You make an annulus of glass that has a hole in the middle and you pick up your piece of selenium on this by sliding your annulus of glass underneath it, and lo and behold, you have a self-supporting film of selenium about a micron thick that is available for you to put in your image converter. Now you can put your metal on first or you can put it on afterwards by evaporation, but it’s all controlled so you’ve made your thing and now you can start doing your experiments on doing this and seeing if it matches the theory, which it does, pretty nearly.

[36:35]
There’s quite a lot of things that have come up over the course of this description, I’d like to break it down a little bit if I may.

Well, I hope that there is, because this was the basis of my PhD thesis. Because after a few years I then went along to Orson Wood, who I’ve mentioned before, and said, ‘I understand you can get an external PhD at London University’. He said, ‘Yes, yes, of course you can’. Everything in my life has been lucky, as I say, it’s often better to be lucky than clever. And I was lucky in that I was at a time when London University was really acting as the spoke of a wheel and there were a lot
of provincial universities that were part of London University and gave London University
degrees; people like Exeter, Leicester I think, and others, I mean a number were not universities
in their own right, they were colleges of the University of London. Later of course it all changed
and they became independent. But one of the results of this was that they, when they gave their
PhDs – they gave PhDs – it was essentially an external PhD and you could do an external PhD
and some of the evidence of this would be in your publications. Well, I went to see Orson and
said I’m interested in a PhD and he said, ‘Yes, that’s perfectly possible, you just have to do some
work that is of the right quality, what have you been doing?’ And I said, ‘Well, I’ve got these
publications’ and he looked at them and said, ‘Bind them and wait a year’. He said, ‘Put in your
application now, bind them and wait a year and then you’ll get your PhD. You’ll have to be
examined on it’. But I’d essentially done it and that’s why those things all go together, it just
goes together and in fact I was able to do a thesis on the conversion of thermal radiation pattern
into visible pictures, which as far as I know was the first time it had been done. And it covered
all those aspects. I haven’t actually covered all of them [38:57] because then there was a question
of how did you, what kind of pictures did you get, and we could just about do pictures of a hand,
but we found that the problem was the ability of the eye to detect contrast. Now, yes, I haven’t
mentioned that have I? You’re looking at a picture, how do you see pictures? Well that’s all part
of it. How do you see something? So we had to go into the physics of how did you see patterns.
And this was well established and it was said that you could detect two per cent contrast. So we
did experiments on seeing what we could detect and even under very good conditions we could
not do two per cent. You can easily make up things. You have a thing called the Landolt circle
which is a circle with a gap in it and you then turn it and you have to say where the gap is, and
then you make the material of the circle more transparent by using a thinner material and your
contrast is going down of course. So you can now see how thin a layer can I detect the gap in. I
could do about three per cent. Walter varied, he could do two per cent occasionally but not
always, I think it depended on what he’d been doing the night before, but he would never admit
that. And we then looked into it and then the theory says you can improve this with binocular
vision, and there were other things you could do to improve the contrast in theory. Of course one
of the things you could do is take a photograph and then do contrast expansion, so we did some of
that. Of course we also had to take photographs for the papers and the records and that meant we
had to look at how did you develop films, how could you be sure that you were always getting the
same result when you developed a film and you put a wedge on for calibration, you’ve got to do
that. And again, Walter developed methods – the developing of plates was something which we
hadn’t appreciated was really quite difficult.
As in photographic plates?

Yeah, you’ve got a photographic plate and you’ve now got to develop it and you really want to ensure that the negative that you’re making reflects the pattern that you put on it. Now that involves a chemical reaction locally between parts of the silver halide that have been exposed to the light, which is not as reproducible as you might think because you’re liable to get local exhaustion of the chemical as you develop the thing, you can’t guarantee that it’s the same. And Walter developed a special tank which had a false bottom, essentially, where the plate was in a recess and there was a blade that you ran across the whole tank so as to stir the material up and you stirred it up and we were fairly certain at the end that we were doing as well as you could do in getting a reproducible gamma, which is effectively what the thing you’re seeking, that your contrast is going to be there. But there are ways in which you can increase the gamma, so in principle you could make it higher. But when you’re absorbing the thing that’s not necessarily going to be what you want. But then there are various ways in which you might improve the sensitivity and I think in my thesis I identified five ways in which we’d increased the sensitivity by a factor of two, and since we reckoned we could readily detect ten degrees, a body ten degrees, which was pretty good then, ten degrees, that if I had my five things I’d get it down to one degree. In fact I tried all five and got it down to five degrees, which taught me that you can’t necessarily multiply improvements one by the other.

[44:00]

There are a lot of questions I want to ask you about the ground we’ve just covered and I’d like to get them before I forget what they all are.

Well, let me just finish with this, because this was of course getting on to 1958 which does overlap, but it indicates what I was doing. This was my own research while I was looking after the rest of the group, because this carried on with me doing this at one stage when Jimmy Edmond and Bob King had decided that there was no future in the tube they were trying to make and when it was agreed as a group that that should stop, and also at the time when Sutton decided that he ought to bring somebody senior in to run a solid state group, that by now there was an interest going in semiconductors and solid state, Malvern had started some work and there were various reasons why we should get into it, which I will go into. But essentially this finished with me writing up my publications as a thesis and putting in for a PhD, which I got and as I’ve
mentioned, McGee from EMI who’d done the RG tube, he chaired the board that actually interviewed me for my PhD, and I got it, as you know.

_I don’t think you_...

So that finishes that part of the story.

_I don’t think you’ve actually mentioned on tape what your interview was actually like for your PhD._

Oh, well of course I’d been a bit worried about it, but I thought it was okay and Orson thought it was okay and he wasn’t the easiest of people to please. I mean I’d been in touch with him, obviously he was my supervisor for it, so it was unusual because there were half a dozen people really from the infrared industry in the country rather than people from academia, because there weren’t many academics involved in the field. So I wasn’t sure what would happen and when I went in McGee said, ‘Well Cyril, we all know each other don’t we?’ And I said, ‘Well yes, I suppose so’. He said, ‘And we all know that essentially there’s no point in us asking you questions because you know more about this subject than anyone here or anyone in the world’. I said, ‘Oh’. He said, ‘Well, so you should, you’ve been studying it for long enough’. I said, ‘Well, yes’. He said, ‘So why don’t we just generally chat, why don’t you chat about how you did this and what your interests were’. So we more or less went through what I’ve actually told you, identifying the interest in each bit, analysing it bit by bit and saying well, this is the physics that’s behind this bit. Actually, I looked at the thesis the other day and there’s some maths in there which I would have some difficulty in doing now. I was quite impressed with some of what I had done there, I haven’t covered all of it, but… The only thing that I didn’t do was heat spread, very well, because Bob and Jimmy had done a thing on heat spread, but I think I could do more on that and more has been done on that now. In fact, the way in which people have solved that problem is that they pixelate, they put things on what are called fakirs’ beds, they make a support that’s a lot of nails sticking up and they put something on it and then they can make something that’s very thin. Alternatively, they actually can separate out the retina into different areas which are thermally isolated from each other. But thermal imagers have come a long way since then, they would laugh at 10°C, they can do better 0.1°C now.

[48:10]
I’m interested in, how we first got on to this topic was with you saying we ought to do some physics on this.

Yes.

That’s an interesting expression, I’d like you to unpack it a little bit more.

I’ve always believed that you can make better devices if you understand how they work and understanding is really a complex word describing a variety of activities which people interpret in different ways. What I mean by that is you understand the processes that are going on in the materials that are used in the device and appreciate all aspects of what is happening. Now, in fact that attitude is not necessarily valid, as I point out to people, it’s a luxury, it’s a luxury which goes down pretty well with the people who are exploiting what you’re doing and want to fund what you do, because it gives them a feeling of confidence that you know what you’re up to. But the best example I can make is probably no longer with us, which is the television tube, and the heart of the television tube is the cathode, and the cathode sends out electrons because it’s warm, but you can’t make it without knowing something about it, that if you just have a metal there and heat it up you’ll have to have the metal almost white hot before you can get enough electrons out. What you have to do is to coat the cathode, which will be a metal wire, with a semiconductor that will have a fairly large energy gap – we’ve talked about energy gaps – that has this property that electrons can escape from it. Now the cathode that was used is a mixture of various oxides; thorium oxide and other oxides, and you found that the people who made it would not tell you what was in it because it was a trade secret and they had arrived at it by pragmatism; trying different things and seeing what worked and gradually coming down and they didn’t all use the same thing. What is more, it sometimes stopped working. And they never knew why it stopped working, they knew there were certain things that they had to avoid, poisons, but they couldn’t be sure of this. So it was a trade secret and this meant that all television tubes were made by people who wouldn’t tell you what was in it because they didn’t really know, they couldn’t patent it and you didn’t really understand in detail how it worked or why it stopped working. So it doesn’t always work that way, but I meant that they didn’t have much comfort and they knew that occasionally there’d be days when the whole thing would stop working and they’d go rushing around trying to work out who had done something which had meant some poison had come into the room where it was done. They didn’t have such clean rooms as we have now, but yes, I’ve always believed that if you understand a material you can make a device. This comes later on
actually, because from a deep understanding of gallium arsenide I was able to make a device which most people thought could not possibly exist.

[51:45]

I’d like to dwell a little bit as well on the doing some physics part of this.

Yes.

And if you think about the explanation you’ve given me for how this actually works, that’s a very sort of physics based explanation, it’s explaining the physics of it. I’m just wondering, what on a practical level do you have to do, other than Walter’s making of the thin films, to actually do the physics of it?

Oh, you have to measure absorption edges and measure the temperature variations of absorption edges, quite an interesting… you also have to measure thermal conductivities. Now this is intriguing because when you do your, when you did your degree you have a practical and in London, I don’t know whether it was in other places, this practical was in two forms. There was the general kind of practical where you’d be repeating practical experiments that you had done and you had to remember what you had done like measure the conductivity of a poor conductor or something, and there was another exercise you were given where you didn’t quite know what you were meant to do, because the exercise was – in this particular case, obviously it would vary – compare the thermal conductivity of a poor conductor with a good conductor given the equipment supplied. Now you thought, okay – and this is in the open lab actually, I will say, where… you’ve got a copper rod, now in principle you’ve got two copper rods, you’ve got a microscope slide, you’ve got some wire, you’ve got some wire, you’ve got some retort stands, you’ve got a Bunsen burner, you’ve got a metre and you have a metre rule, and you’ve got two pieces of lead, two little clips of lead. Now, the first thing you think of is well, I’ve got to measure, it’s a poor conductor, the good conductor must be the copper rod, that’s the only thing that’s a good conductor here. I can’t see a poor conductor lying around except the microscope slide. Oh, well maybe the microscope slide is a poor conductor. What else can it be? Nothing. Must be the microscope slide. Oh. Oh, so I see, what I do is I support on the retort stand the two rods of copper and I put the piece of the microscope slide in between. Oh, oh I see. Well, now what I’ve got to do is I’ve got to heat the copper rod, that’s right, I heat the copper rod with the Bunsen burner and then the temperature will go pretty well along that until it gets to the
microscope slide, and then it'll drop, but even so, some will go through to the other copper rod and then… if I measure the gradient, the gradient of the temperature on the one, I’ve got to measure the thickness. Oh, they’ve given me a micrometre, so I can measure the thickness of the microscope slide, right, and I can measure the thing, so I can measure that. Now how do I measure the temperature? I’ve got this wire here. Oh, maybe the wire is constantan and the lead is the other metal, but how do I connect up the lead so I got the contact with it. Oh, don’t know about that. How do I do the lead, what’s the lead for? Now meanwhile of course, most of the other people were looking at me as to what I was doing and there was a girl next to me who was also watching what I was doing and there was a girl next to me who was also watching what I was doing, but then I noticed that she had put the copper constantan as a loop and she just hung the lead on the bottom of it so as to pull it straight. I thought oh, that’s what the lead’s for, the lead is to actually hang the copper constantan, and it’s a copper constantan thing. You’ve got the copper rod and you’ve got the constantan, so you’ve got a thermocouple, so you’ll get an EMF between the copper and the constantan.

*What’s a constantan, sorry?*

Constantan is an alloy which is used in thermocouples. It’s pretty standard. You didn’t need to know what it was, you just knew it was actually a metal that would give you a high thermal electric force. So, there you are, that’s what you could do, you just could measure this along and do it. And that was what I did and what the rest of the class did for their exercise, and I don’t know what the others did but mine worked out all right, so I was able to compare the thermal conductivity of glass with copper. Anyway, some years later, this was at least seven years later, maybe eight years later, I had to measure the thermal conductivity of selenium and when the group said, ‘Well how are we going to measure the thermal conductivity of selenium?’ I said, ‘Oh that’s easy, you just do this, you set this up like that’. And they said, ‘God, how do you know that?’ I said, ‘Well, everyone knows that don’t they?’ It’s comparing, it’s a standard method of measuring, comparing a good conductor with a poor conductor. So I went up in their estimation, you see, all because of luck, just had done it. And even published it. Yeah, thermal conductivity of selenium, yeah, good thing, yeah. So, that’s what I mean by the physics and you go into the physics of every aspect of it that you can. [58:40] And that’s what you’re supposed to do for a thesis, but on the other hand that’s what you’re supposed to do if you possibly can when you’ve got the time. This was the point, we had the time, nobody was on our necks sort of pushing us to get results or anything like that, we – they knew we were working hard and they knew it was relevant and it was relevant to what Jimmy and Bob were doing too, but in the end it was clear
that what they were doing was too difficult and wasn’t going to work. I mean all the aspects of it were too difficult.

*How much freedom did you actually have to do your own research at this time?*

Pretty absolute. We were an infrared group, as long as it was infrared, that’s what we were doing. I don’t know what Frank was doing actually, thinking about that, because I don’t know that he… I’m pretty certain he was not working on lead selenide. [pause] Yeah, I’m pretty certain he was still working on chemical deposition of lead sulphide, trying to improve it. Of course, there were people still interested in lead sulphide, as we’ve said, for the missiles. So that was perfectly reasonable. As far as the rest was concerned, nobody was bothered. In principle I was still looking after the medium weapons sight. I was, we had the infrared tube and they knew we were doing some research on lead sulphide which fitted in with the missile. But then things did change and this must have been ’54 I suppose, roughly, I’ve got… might have been ’55. Yeah, it was probably ’55. [1:00:50] We now retract for a moment and start talking more generally. The transistor had been invented and people were interested in it. Since there weren’t many people in the system that knew much about semiconductors, we were obviously going to be involved and I’ve said the absorption edge work had got us interested in semiconductors, the work on the medium weapons sight meant we had to get interested in photo cathodes and that kind of semiconductor. So we were the part of the system that knew a bit about semiconductors. The organisation, CVD, which we have mentioned, had to start taking more of an interest in germanium and silicon, so we got involved a bit in that but not much because Malvern were really looking after silicon and had started quite early and were doing some quite fundamental work on silicon and also they’d worked on germanium as microwave modulators, so they were heavily involved. But it was thought that the Admiralty Lab ought to do something. So Sutton was persuaded to recruit a man, a senior person, this was, as I say, foreign to him but he had pressure on him to bring in somebody who could set Baldock up into semiconductors. [1:02:40] And we had to have a decision as to what did we do to get into semiconductors. And we couldn’t really go into silicon because Malvern was in silicon, but at that time people were starting to think about compound semiconductors and Siemens had been doing some work on III-V compounds. So there was a big meeting we had and it was reckoned that we ought to start working on III-V compounds. Now, that made some sense as far as the missile was concerned because the III-V compounds, by which I mean compounds made from a binary combination of elements from the third and fifth group of the periodic table which come either side of the column
that has silicon and germanium in it and you could show that if you used the heavier elements
like indium antimonide you could make a semiconductor whose energy gap was smaller than that
of lead sulphide or lead selenide, so it would take you well into that 3.5-4 micron window and
even a bit beyond that. But nobody had done it. It also was a very interesting semiconductor in
that the speed with which electrons move in it for a given voltage is very high. The typical values
that you have are around 1,000 is the figure for silicon, 3,000 the figure for germanium, which
was the material that was being used for transistors at the time, and is 78,000 for indium
antimonide. This is the way it goes, that the heavier the element you use in general the electrons
to travel faster. So we had the idea and so did Malvern that maybe we should start working on
indium antimonide and try and, we had the idea, and should try and make photocells from it.

Well, we were also interested in the galvanomagnetic applications of indium
antimonide, which is what happens when you apply a magnetic field as well as an electric field to
the material. This is a pretty standard measurement that you make in semiconductors as to what
happens and in fact if you have a high mobility, which is the number I was giving you, it’s the
product of the mobility and the magnetic field that gives you galvanomagnetic applications. So
we thought this was worth working on. We also thought we ought to work on a material with a
high energy gap because we really wanted something that was better than germanium. Now,
germanium was used for the first transistors and up to, from ’48 to about ’60-odd… [pause]
Yeah, until ’65 it was the main material that was used for semiconductor circuits. The problem
with germanium was that it didn’t function very well at high temperature. Its energy gap was
such, it worked in the intermediate infrared and if the temperature got much over 60°C it
wouldn’t work very much, you got too many electrons excited from being attached to the atoms
to being free, so it would confuse the performance. Well, you might think that most things don’t
work above 60°C, but 60°C is the temperature of the device, so if you actually wanted to make it
work hard with much power, you obviously would get heat generated. So they wanted something
that would have a bigger energy gap, and the natural material for people to go for was silicon. So
almost from the early fifties, people were interested in silicon, which is why Malvern had started
work on it and in fact actually at this time that I’m talking about, ’55, there still were no silicon
devices around. There were, by ’57, they were selling, oh something like three per cent of the
devices were silicon and they were twenty times the price, so they were pretty rare devices. But
we thought that we ought to really look at this and see whether we could do something and it was
decided, and I stress it wasn’t me, because what I suggested was rubbish, as it proved – and I’ll
tell you that in a minute – it was thought we should work on gallium arsenide. Now, the reason
why you work on gallium arsenide is because you’re looking for something which is really
germanium-like but better. And it’s a fact that if you take an element in the fourth group and you now go to the third and fifth groups for your binary compounds, that you’ve obviously got three alternatives. For germanium you’ve got aluminium antimonide and aluminium is higher than germanium and antimony is lower, you’ve got gallium arsenide which is the two elements that are level with germanium, and then you go the same way and you go down for a heavier three and five and you’ve got indium and phosphide. And if you look at those and say what is the choice, it is fairly obvious that aluminium antimonide is the one to go for. Aluminium is very common, antimony is a reasonable element, low melting point, not toxic. On the other hand you look at the others: gallium arsenide; gallium is very rare, it’s an impurity in aluminium, rare and expensive. Arsenic, well, who the hell wants arsenic. And then you go to indium phosphide. Well, indium is fine, that’s plenty, but phosphorous, I mean it’s poisonous, it’s explosive and it’s got a very high vapour pressure, so you obviously go for aluminium antimonide. That’s when nature laughs at you, because if you make aluminium antimonide, which you can readily do, it’s got the lowest melting point, and put it in the drawer, in the morning you’ve got a pile of dust. The effect of water vapour just, shhh, just dissolves it, and nobody’s ever really solved it, even now, fifty years later. People don’t work on aluminium antimonide. They may do, they use alloys of it and things, but aluminium antimonide as it exists is hardly done. Also turns out that it’s p-type, for reasons which we don’t understand, nobody ever made it n-type. In general it’s a mess.

[1:10:45]

*What are p-type and n-type?*

N-type is where your conductivity comes through the electrons, p-type is where your conductivity comes from holes, which is the absence of electrons. You get, you can get a sea of electrons moving and you won’t be able to detect it unless there’s some missing in the pattern, and then you get a change in the charge as it moves along because of the vacancy and it’s easier to do the analysis by suggesting that what you’re getting is a hole, which is a positive charge that is moving and the analysis works perfectly well. I had a chap in my group called Herbert Dees, who refused to accept this, and he worked everything out on the basis of a cloud of electrons moving with the odd vacancy. He got the same answers that I pointed out to him, he was getting the same answers as using a hole, but it was taking him twenty times as long. He said ‘yes’, he said, ‘but fundamentally I’m more happy with it.’ Herbie was a mathematician, charming chap.
Before we go any further as well, I just think, you know, in the interests of people who may not know what a semiconductor is, for instance, listening to this, would you mind just briefly defining a transistor to begin with. We’ve talked about valves quite a bit, but…

Well, first of all you have to start off with a semiconductor. A semiconductor essentially is a material whose conductivity is less than that of a metal but more than that of an insulator. But that is not really the point, the point is that you can control the conductivity by putting in impurities in a very controlled fashion, because if you have a very pure semiconductor it will be an insulator at low temperature because there are no electrons available which can move and that you can actually accelerate or decelerate. But what you do is if you put an element from the, if you take a III-V compound, which means you’ve got something like gallium and arsenic, and now you add something as an element from the sixth column of the periodic table, you have an extra electron available. That material, which might be sulphur or selenium, will sit in the lattice in the same place, but when it sits there a spare electron will be available. It will be attached to the atom but because there is a high dielectric constant in the material, the orbit of that electron will spread over many lattice sites, so it’s very easily detached and will wander through. In the same way, if you have something – I’ve got it the wrong way round haven’t I? The arsenic actually is in the third group, it’s the zinc that’s in the fifth group, sixth group. If you have something now from the second group you have the absence of an electron, you have a hole and you can think of it as electrons filling the hole or you can think of the hole as being a positive charge, which again can move through. So having these positive and negative charges available to you, you can make devices that work if you know what you’re doing. Now a transistor is made by having, well first of all we should say what happens if you put a p-type semiconductor next to an n-type semiconductor. Then you have a diode, obviously, because it’s got two electrodes, but it’s a rectifier. Now, if you make the n-type region negative you will drive electrons into the p-type region and they will carry through. But – and extra electrons will come from the electrode so it’ll have a low conductivity. If on the other hand you make the n-type region positive, you’ll be sucking the electrons out, but there won’t be any electrons coming in from the other side, so it’ll have a high resistance so you’ve made a switch, a valve, essentially, a rectifier. Now, that’s a simple device but it’s a very useful device and people do use diodes and they’re quite easy to make, you just have an NP junction. If you actually now put another n-type region on the other side of the p-type so that you’ve got an NPN junction, what you can do is by making the, one of the N regions negative you’ll drive electrons from one side through, if the p-
type region is very thin – and it has to be very thin – before it knows it’s got electrons in, the
electrons have moved into the PN junction. Now, that PN junction will be biased if you’ve
chosen your biases right, so it’s high resistance. So what you have done is you have injected a
current from a low resistant circuit which was your PN junction forward biased, into a high
resistance circuit, which is the PN junction that’s negatively biased. So what you have done is
you have transferred current between two resistors and the current in the high resistance part will
have a high voltage, because you’re putting current into a high resistant circuit, so you generate a
high voltage. So you’ve made a voltage amplifier and you’ve made it by a transferred resistor
circuit, so you’ve got a transistor. And that’s what a transistor does, it actually moves current
from a low resistant circuit to a high resistant circuit.

What can you use one for?

Well, I’ve just said, it gives you voltage amplification. It also gives you…

What use is that?

Mm?

What use is that, what sort of applications can you put it to?

Well, that’s the way in which many electrical circuits will work, as amplifiers. If you have an
amplifier you can then, by taking part of the output back into your circuit, make an oscillator, so
you can make something oscillate, make a current oscillate at high frequencies, which can give
you radio waves, or if you’ve done it the right way you can even get a radar system out of it. It’s
one of the systems. Transistors can work at different frequencies. All electrical circuits rely on
amplification, switching and oscillation. It’s also very easy to make a switch, your rectifier is a
switch. It’s the way in which you combine these things that gives you the powerful circuits.

[1:18:45]

What’s the advantage over using a transistor over a valve?

That of course is fairly obvious. Valves are very good devices if you’re not short of space, and
people worked for years on trying to make them smaller, the problem with a valve is that it does
require that cathode I was talking about, which is hot. It is not too much of a limitation having something that’s hot when it’s in the middle of a big vacuum, but if you try and make a small device that’s got part of it hot, it’s going to heat everything up and it’s not going to be very comfortable, particularly if you want to change one. But it’s, the heat is going to be a real problem. Also, it’s quite difficult to combine them. Now, the power of the transistor wasn’t actually in the individual circuit so that’s pretty good and can be quite small, it’s in the fact that you can combine them by what was later called a planar process, by putting them all together on one surface. The other real advantage they’ve got, the very powerful advantage, is they work off low voltage. Now, a vacuum tube, an amplifying vacuum tube has an anode, a cathode and a grid and to make them work well you really need some tens of volts between the anode and the cathode, whereas a transistor’ll work perfectly well at two, four or six volts, so that makes it much easier. They’re also pretty efficient, transistors. What else is there? They’re easier to make. The vacuum tube has problems that aren’t obvious in its nature but it’s when you come to think of it practically that you cause problems. The cathode first of all, you’re heating a wire up, it’s got an oxide on it, but there is a wire there, and in time it will break so the device gives up and if you get a thousand hours out of it you’re lucky. Then in any case the electrons only travel well in the, between the anode and the cathode, well between the cathode and the anode, because it’s a good vacuum, but how do you keep a good vacuum. In principle if you make the thing perfect you will have a good vacuum, but in practice there’s so much that can go wrong when you make it without guessing from the various things, unless it’s really made very carefully indeed, the vacuum will go. So again, it will start losing its performance. Then you’ve got a glass envelope. I remember many years ago, I told you over lunch that my best friend worked for RCA and he actually worked on gallium arsenide and we knew everything he was doing, and one of the things that we were doing – which we’ll come to later on – was light emitting diodes. And I went to see him on one visit, I paid a number of visits each year to the States, and went to see him and he said oh, he’d been promoted and one of his responsibilities was a device called a Lumitron. I said, ‘What’s a Lumitron?’ And he said, ‘Well, it’s this numeric device that essentially works as a vacuum tube and you get a plasma discharge inside it which you arrange in various paths and by working the electrons then you can get numbers coming up’. And I said, ‘Well, it’s surely not as good as the normal numeric we’re getting from semiconductors’. He said, ‘Oh it’s very bright and it’s very, very cheap, very cheap’. And I said, ‘But it’s got a glass envelope, isn’t it fragile?’ He said, ‘Watch this’. And he took one and he said, ‘Look, it’s working’. He puts it in and he threw it down hard, he threw it on the floor and it bounced and he picked it up and said, ‘Now watch’ and he put it in and it didn’t work any more. And I said, ‘Well, what did you expect?’ He
said, ‘I’ve done that ten times’ he said, ‘and it’s worked every time’. He said, ‘The difference is, each time I managed to throw it so it hits the mat, not the floor, and this time I missed the mat’ he said, ‘so it wasn’t very convincing’. I said, ‘No Len, it’s not convincing’. So, yes, the glass envelope is a nuisance because it breaks. So these are the problems with vacuum tubes. Now, they’re not overwhelming problems, people have made metal enclosures instead of glass, they’ve made miniature tubes and they’ve been quite rugged, they have been used in anti-aircraft shells and things, so yes, it is possible to get over them and you find they are still made today for sophisticated music centres where people reckon the quality you get from vacuum tubes is still very high and they still are used for very high powered devices and of course in some radar systems with very high frequencies they’re still used. So they haven’t disappeared entirely. But the markets are quite different now and you cannot do with a chip what you can do – no sorry, the other way round – you can’t do with a vacuum tube what you can do with chips. The first computers, one of the first computers I went to see, I think it was called EDSAC, at Cambridge University when Maurice Wilkes showed me into a room which was very warm, he had hundreds of the devices. And I said, ‘How is it all going?’ And he said, ‘Well, it’s fine when they all work’ he said, ‘but you only really get about one hour out of the total system because one of the valves will pack up and if you’ve got several thousand of them, then it’s likely that one will go more or less every hour, so it’s a big nuisance. But it’s the only way we can make them’. It was the only way they could make them then. So it was logical and inevitable that there would be a move to solid state, just in the same way as there has been the move from cathode ray tube displays, which were remarkable devices, give perfect images, to flat panel displays. But there is a difference, of course there you’ve gone to a liquid rather than a solid, which is another story we will get to.

[1:26:15]

*I think I’d like to take a break in a moment, but again there are a few things that have come up in passing…*

Go on.

…which I think we need to do before we move any further on, and one of them was actually a question I meant to ask a little while ago, which is you’ve sort of mentioned sort of committees, groups and meetings and this sort of thing and I was just wondering, you know, obviously for some people meetings are just meetings, they’re just boring things that happen, but I was
wondering if you can give me an idea of what does happen in, let’s say a meeting of the Joint Infrared Committee, for instance.

Oh. Well, obviously there are different committees, there were the laboratory committees where we would be talking about the progress of different projects and where we also would be dealing with personnel matters if people maybe wanted to transfer between groups, new things happening. I can’t remember finance but I’m sure we discussed finance, we will have had to discuss finance at some stage. Then there were the CVD committees and those were fairly practical in dealing with how we were going to spend the money, just we had projects coming up. All the money was for external contracts and we had projects being proposed. Once a year all of the companies would put forward proposals for work on different topics and say how much they were going to cost and how many people were going to be working on them, and that would be a straightforward decision, arranging things in order of priority and deciding who was going to monitor them. The Joint Infrared Committee was a little bit strange, it was unusual and really was there only because there were two establishments working and the system wanted them to function well together and it had been decided that would be by this committee and it was very unusual that it was somebody as senior as Bill Cook looking after it. And similarly, very odd that someone as junior as me should be on it. It was, I suppose, essentially a political committee as opposed to the others, to ensure that the people worked together as much as they could. I was too naïve to know too much about it. I think it was a question really of the Ministry of Supply and the Ministry, I suppose, of Aviation, which was who Malvern was reporting to, they were Supply and then they became Aviation. Trying to ensure that they had a role to play, which they never had had. You see, all the infrared had been done by the Admiralty, that there were two establishments involved. There was Teddington and there was Haslemere, that was it, the… Malvern was radar, essentially, that was it. I don’t remember them doing any infrared at all, so their infrared interests came much later and I think came largely because there was beginning to become an operational necessity rather than it was a natural home for them. I don’t know, but I have…

What sort of things would you be contributing to a meeting, of say, Joint Infrared Committee as we’re on that one?

Well, there were two. As far as I remember, the first ones were basically simply reporting on the way the detection experiments of where we had got to, because there we were doing the work, we
were really running the trial. We were helped by the National Institute of Oceanography, which was running the device that was under the water, and of course Malvern was doing the Yellow Duckling. So it was a three-establishment thing, so it was reasonable there should be a body that wanted to know what was going on. Then it got into the lead sulphide cell for the missile and that was, I suppose, a much higher priority.

*What were the meetings actually like to sit in for a junior scientist like yourself?*

[pause] I suppose I thought a lot of it was a waste of time, in that I couldn’t quite see why we all needed to come up to headquarters to talk about things which we talked about anyway. It was more a question of informing the more senior people of what was happening. In fact later on when the missile work became quite important, a sub-committee was set up, as I said, which consisted just of Robin and Frank Jones and me and that was okay, that was essentially hammering out what it was we were doing and what future work was going on. And that developed later on, as we’ll say, when it got more past lead sulphide.

[1:33:00]

*I was going to ask as well, just thinking about what it was actually like working at Baldock, and you mentioned quite a few other people in passing, but I was wondering, were there any women working there as well?*

There were women working there, if you mean women scientists… [pause] I can’t think of any. I’ve said there were certainly some women doing physics when I was doing my degree, a fair fraction of the class was women because the men weren’t, well, half the men weren’t allowed to stay on. But most of those I think went to academia. I’m trying to think what women there were, if any. [pause] I think there was a woman chemist, I have a feeling there was a woman chemist. There were no women in my group, I’m pretty certain. There may have been lab assistants. Later on I don’t think there were any women scientists. I do remember the people who were recruited and certainly none of those were women. I don’t think so, I don’t think the establishment had any women scientists. It had quite a lot of women assistants and women technicians, but I don’t think any of them would have had degrees.

*Did you ever think that was unusual?*
No. Never thought anything was unusual really, just carried on with what I was supposed to be doing. Found all life to be unusual I suppose, I didn’t find that more unusual than anything else.

[1:35:26]
_I was wondering as well, you’ve talked about sort of working with technicians along the way quite a few times._

Yes.

_You talked about yourself starting off as a technician then being promoted to Scientific Officer and I was just wondering, is there any sort of, let’s say class division between the two groups at all or do you just all get on with it?_

No, you all got on with it. There was a difference between your responsibilities and that you knew that you were supposed to be coming up with the strategy and the ideas of what you were doing, but very often it was the people, the technicians who would actually decide how to do it, they would be the people skilled in laboratory practice. That doesn’t mean to say that you wouldn’t know how to do things, you would know how to evaporate thin films, how to work an evaporator, how to do things, but as often as not, they would do it because they would do it better than you. But I’m reminded, I said that we had decided that we would stop the infrared tube. Now that was a group of three, I mentioned, it was Jimmy Edmond was the leader, was reporting to me, Bob King was, he also had a degree, he’s second in command, and there was Eric Francis who was the lab assistant. And I think it was after two years, it must have been, they were working very hard and trying to do the thing. Now, they made their glass thin films in a very complicated way, it was almost made from the silicon oxide which they would prepare and they would heat up and I never quite got to grips with how it was being done, but anyway it was quite complicated. Well, after a time - we would have frequent discussions as to the problems and what was happening and after a time they were getting depressed and we were beginning to move into other things which I will come to in a moment and I said to them, ‘Well, what do you think about this, what do you think, how long should we go on?’ And we had various deadlines, which normally you get to a deadline and you say well, we’ll give it another month or we’ll give it another week, and after about the third time of giving it another month you’d say, well, really is it worthwhile going on, we’re no better off now than we were last year and it doesn’t look as though… and there’s better things we can do with our time. We decided that we were going to do
something different and I’ll soon tell you what it is we were going to do that was different. Well, I was in the lab and I wanted something, and I forget what it was, and I said, ‘Eric’ – that was the lab assistant – ‘Can you come and give me a hand with holding this because I need three hands’. And he said, ‘Yes, I’ll be with you in a minute Cyril’. I waited for a bit and I said, ‘Eric, Eric, I’m waiting, what’s going on?’ And he said, ‘I won’t be long, I won’t be long’. I said, ‘Oh Eric’. So I put down what I was doing and went over to see what he was doing, and I said, ‘What are you doing Eric? You’re at the sink’. He said, ‘Yes’. I said, ‘You’re not still making a glass film are you?’ He said, ‘Yes, I am’. I said, ‘Eric, we gave up that project two weeks ago’. And he said, ‘You may have given it up, they may have given it up, but I haven’t given it up’. That was the lab assistant. I did have to explain to him that he really could not carry on with the project on his own, that there were good reasons why we had given it up. But I wouldn’t actually have put it past him to have come back in the evening and still made some glass films.

Another question I had was about computing and did you actually have computing facilities available to you?

As you say, there’s an anecdote here, an anecdote. I was in Fanum House and it was sort of three months I suppose after the war ended, and I was sitting in the office reading reports when there was a knock on the door and a chap, a naval rating, or he may have been a rank, popped his head round, he said, ‘Do you know where the Ministry of Pensions is?’ I said, ‘I’m not sure’ I said, ‘I suppose it’s in a lot of places, where did you mean?’ He said, ‘Well, I’ve got an address here, I don’t know where this is’. He said, ‘It’s not definite’. I said, ‘I can look it up though, I’ve got a book, I can look it up’. I said, ‘Why do you want the Ministry of Pensions?’ He said, ‘Oh’ he said, ‘I’ve got a lot of calculators here, Brunsviga calculators here’. I said, ‘Oh’ I said, ‘How many you got then?’ He said, ‘I think I’ve got fifty’. I said, ‘Oh I know what that is’. I said, ‘I’m glad you called here, they’re two for us and forty-eight for the Ministry of Pensions’. He said, ‘Yes’. I said, ‘And this is this address to take them to, so bring the two up for us and then go off’. He said, ‘Fine’. So he brought in two Brunsviga calculator machines. Those machines followed me around for several years. I left one of them with a chap who I can still picture, his name was Verra or something like that, a mathematician, at Teddington. I took the other one to Baldock and nobody knew where my Brunsviga calculating machine had come from. But I carried it… I didn’t know what to do with it in the end because we did go over to electrical
calculating machines, the Marchants, but of course we were way before computers. But we had to do, all calculations were done on slide rules. And they took a long time, yeah.

*Did you have any sort of maths section support then?*

No, we were the maths section. I mean people would bring things to us to calculate. There was a maths group at Teddington, there certainly was a maths group at Teddington. I don’t know what they were doing. There was a man called Vadja - V-A-D-J-A – who was a very serious mathematician. But they will have, you see Teddington was mostly concerned with underwater propagation, so they would have needed some pretty advanced maths. There must have been some calculations needed on magnetron orbits and things like that at Malvern but I don’t remember anybody being embarrassed and I don’t think there were any mathematicians there. Later on one did come from Malvern, a man called Shersby-Harvie who was an excellent mathematician and I still remember once we went over to a meeting at the subsidiary lab that Sutton opened in Harlow where somebody had a new idea on a vacuum system, a radar system, a microwave tube which used plasmas in a certain way, and he gave this presentation and then he said, ‘Well’ he said, ‘that’s how this thing works and it amplifies and it’s much better than what we’ve got. Are there any questions?’ And Shersby-Harvie put his hand up and said, ‘What about Poynting’s vector?’ And the man stared at him. And we all stared at Shersby-Harvie and somebody folded their book up and said, ‘Yeah, that’s it isn’t it’. And off we all walked. It was impossible. Yeah, just like that. How about… I thought that is masterly, I wish I could do that at a meeting, just stop a meeting with a question like that, but he did. Mind you, he wasn’t always very practical. He had an old car and somebody once pointed out that there was grass growing in the back seat. He said, ‘Oh that’s because I went… I carry grain for my daughter’s horse in this car and the other day I went across a ford that was deeper than I thought’. He had grass growing in the back seat. Not scientific, but he was very clever. But there were other people who were theoreticians, although most of them could turn their hand to practice as well, but there was no mathematic section.

[1:45:06]

*What sort of contact did you have with other groups up at SERL?*
Oh, that was complete. Everyone talked to everyone, it was a small establishment, everybody knew everybody. There was one exception, which I’ll come to in a minute, but as far as the microwave tube people were concerned they were all very interested in what we were doing in solid state and Harry Boot, one of the inventors of the magnetron was there, and he was always very open and friendly. Yeah, that was that. There was one part of the establishment which was developing a neutron tube that was going to be used as the trigger in the hydrogen bomb and that was very secure and a separate building was built for it, partly because you couldn’t have that power of neutrons flying around everywhere, but also because it was easier to keep it secure, that was at the far part of the establishment. There was a group set up specially for that. They were, they did try, there’s no security about that now, because Sutton was trying to find civil applications for it, when the need for it vanished he tried to use the group for civil applications and it was thought at one stage that it might be useful as a cancer therapy, but I don’t think it ever proved practical. But that was the one exception, where you did not mix with those people at all, that was too classified.

What sort of interactions do you have then, if you’re allowed to mix with everybody else apart from that?

Well, you couldn’t help interact because it was a, it was a converted factory and was more or less called the shed. It was a big shed, there were no partitions. The infrared group was in a hut outside mostly, I’m trying to think – the Secco hut, that’s what it was called – S-E-C-C-O – Secco hut. But there were offices at the front so if I was going from the hut to my office I’d be going through the shed and I’d see people and you’d say, ‘How’s it going, what’s happening?’ and they’d tell you. People would want to talk about what they were doing because they always through that they might get ideas. It was very interactive.

[1:47:55]
What’s the… is there any social life attached to working there as well?

Well, that was quite good. The establishment itself prided itself on ensuring there was a social life for the staff and the wives and children. There was no inhibition at spending time and money at Christmas. I seem to remember that we made a carousel – I didn’t – but somebody made a carousel with fluorescent tubes coming out from it that went round and round and the kids came at Christmas for the party. There were summer dos. Baldock is not really big enough to be a
town, it’s a village, basically. It was on the Great North Road, now it’s bypassed. And many of
the staff were in one of the two hostels. There were two hostels; one was called The Brewery,
which was a converted brewery. That was on the Great North Road and was only about 400
yards from the establishment. And just round the corner there was a big house, whose name
escapes me at the moment, I had it a minute ago, but it’ll come back, which was I think slightly
better class than The Brewery, in the accommodation, not in the people there, they were all
mixed. And again, there were a fair number of people there. A lot of people were single. There
were some married couples, particularly obviously in some of the older people who’d been in the
system for longer, but it was a pretty young establishment. And there was an active social club. I
did a lot of playing chess there. There was an interesting atmosphere locally because Letchworth
itself was quite a technological centre but it had other factories and organisations there and for
some reason, I don’t quite know why, there was quite a high proportion of educated immigrants
there. Some, I suppose, were refugees from Germany. I remember particularly there was a man
called Gottfried who certainly was a refugee from Germany, but then some of them I think had
come from Eastern Europe, there was one Hungarian as well. Gottfried I remember because he
was a very good chess player and a very polite gentleman and he had a PhD from a German
university, obviously, but he was the accountant at the local woodworks. I said to him, ‘I mean,
why aren’t you practising your talent?’ He was a chemist. And he said, ‘I’m not allowed to, I
have to work where I can to make money’. And that was true, also there was a man who worked
in the local lace factory - lace? - it was materials anyway, it may not have been lace. But he also
worked there. There were some who did work at British Tabulator which had come from
Hollerith, which later became Fujitsu or something like that I think. But all of them had a passion
to improve themselves and wanted to play chess at quite a serious level and it so happened that I
was then quite good at chess and I was always faced with really passionate matches where people
were really serious and could get quite petty about it. I remember I was playing one of the people
from British Tabulator I think, the matches were matches three-a-side and I played top board for
our side and I played somebody and he, I was quite pleased because I’d beaten him, and that was
in the individual, not in the team match, and he put in a complaint that I had taken too long over
my moves. And I said, ‘Well, I don’t doubt I took too long, but I did offer him clocks at the
beginning and he said it wasn’t necessary’. And they said, ‘Mm well, even so, he claims you did
take too long and it put him off’. I said, ‘Well, I’m quite willing to play him again’. And I went
back and I moaned to Betty about this, ‘I’ve got to play him again because he said I took too
long’. And she said - well, now, when we played individuals we would play in each other’s
houses, the team matches were played in halls, but for individuals you visited someone’s house
and you took turns at this - and she said, ‘Well, he’ll be able to say exactly how long you took
and how long he took because although you weren’t using clocks he wrote it down on his score
sheet’. I said, ‘Oh did he, I didn’t notice’. She said, ‘Yes, yes, I noticed that when I brought you
in some coffee, that he was busy writing it down’. So I rang up the secretary, I said, ‘Look, I
mean if Donald is really worried about this and he thinks I’ve taken too long, he can produce the
evidence. I don’t mind playing again, but he’s got the evidence on his score sheet’. And he said,
‘Oh well that’s good, that’s good, I’ll get more facts then from him and we’ll do this’. I said,
‘Great’. So later on, he rang me up, he said, ‘I’ve been on to Donald’. He said, ‘No, he hasn’t
still got it, he rubbed it out’. I said, ‘Ah well, pity. Well, never mind, I’ll play him again then’.
So I went home that night and I said to Betty, ‘No, it’s no good. Good idea, but he’d rubbed it
out’. She said, ‘That was clever’. I said, ‘Why is it clever?’ She said, ‘He was writing in ink’.
And I said, ‘Oh leave it, leave it’. It was ridiculous. I played him again, I beat him I think. But it
did mean, it was part of the social scene but it was pretty passionate that there and they really,
when you heard their stories, they were really very nice people who were managing at levels that
were not up to their intellectual capability by any means. And we couldn’t recruit them of course
because of security.

_Shall we take a break?_

By all means, yes.

[end of Track 8]
Just a quick clarification question again. Why were you visiting Maurice Wilkes?

I think I was visiting Maurice to see really what modern computers were doing. We had no facility for complex computations at Malvern, I can’t remember us needing them, but – sorry, at Baldock – whereas at Malvern they did have a computing section and they had a very good computer which I used extensively later on. But I suppose I was looking round to see what there was available more or less locally, Cambridge is not very far from Baldock, so I’d have been visiting Maurice to see what was happening there.

Where were you actually living up in Baldock? You mentioned hostels – were you there or somewhere else?

It varied. Remember, I was at Baldock for thirteen years. It started off in digs in Stevenage and then there was a flat in Hitchin which is about five miles away, at that stage we didn’t have children. And the system always had access to some prefabricated houses for accommodation and one of those became free, I imagine after about two years of us being in the area, and then we moved into a prefab which was within about 300 yards of the establishment, just down the Great North Road. And that was very comfortable for a bit. We were okay until we had our first daughter, but then we realised when we had our second that we needed a proper house, so we had one built in Hitchin, which is where we lived for some time until we moved to Malvern.

When were your daughters born?

When were they born? Make sure I get this right, otherwise I’ll be in trouble. Karen was born in ’55 I think, ’55 or ’56 – ’55 I think. And Lin was born probably three years later. I think that’s about right. Maybe four years later. Round about then, between ’55 and ’60, both of them were born.

Could you give me a little insight into what domestic life was like in the Hilsum household?
I’m obviously not the best person to ask what it was like in the household. I used to work fairly hard, certainly when we lived in Baldock I would often go back in the evening and work. I don’t think I did that so much when we lived in Hitchin, but I probably would have worked – I didn’t realise I was working hard until more or less later on in my career when I would be talking to some people who used to work for me and they would comment that they were put off by how hard I worked. I was never conscious of it because I was always interested in what I was doing and it never struck me that I should be doing other things. That must have affected my domestic life, which I was never terribly conscious of until after my wife died, I did actually say to my younger daughter that I now regretted the fact that I had spent so much time at work and which involved such a lot of travel. And she said, ‘Not in the least, your doing this opened so many doors for us and we had so many opportunities of seeing other things’ and one of the things that we did, which obviously came later, was we insisted that our daughters should travel and should see other people and it so happened that we had these contacts through my work with people in France, Germany and the States and there were exchanges and the kids did travel quite a lot. At that time, because this was obviously when they were in their, well, before they were thirteen or fourteen, and in fact they still do – well, Karen is dead now – but Lindsey still has contacts with some of the people from those times and I’m still in contact with at least one of the daughters. Well actually, my best friend is in the States and I still have contact with him and know about his children. Yeah, life is complicated, you can’t always say how things will turn out. And I can’t pretend that I was other than selfish, essentially I was doing what came naturally to me and quite possibly I wasn’t considerate enough of the family and those things, well that’s how it happened.

*Did, well let’s say your wife, ever mention your working hours at the time?*

No. No. She… [07:35] She worked for quite a lot of the time. We tried to make sure that she kept on with her career, particularly when she came to Malvern, that was later on that we had domestic help so that she was able to do things. She certainly did not develop her own career as she could have done, she could well have become a headmistress of a big school. But in fact she finished up as second mistress at Malvern Girls’ College.

*You’ve mentioned Betty a few times, I still don’t quite have an impression of what she was like as a person.*
Hm. Delightful. Very cultured, very outgoing, very considerate of people, very popular. She was much more of an artistic bent than I am, I mean she liked going to the ballet. We both went to the theatre quite often but the ballet was not my thing, but she would go with friends. We were a good couple and she died too early and I think partly because she didn’t look after herself, too much involved with me, in the sense that she got cancer and it wasn’t treated correctly and we weren’t conscious of the fact that the early operation hadn’t gone right.

_I wonder, if you were doing secret work, how much of your job can you actually discuss with her?_

Oh, I don’t think, no I didn’t discuss very much with her. Well, it was very technical, remember, and she was a French graduate, she had very little scientific knowledge. She was pretty good at languages – French, German, English – and taught quite a lot, all of those at quite a high level, but I don’t think she was terribly interested in the scientific side, so it didn’t happen. Much of what I was doing wasn’t secret anyway otherwise I wouldn’t have been able to publish as much. Obviously the missile stuff was and there were some things later on in Ireland that were obviously secure, but no, if there was something that was secure I wouldn’t mention it to her and she didn’t want it to be mentioned.

[11:25]

_With your sort of domestic life with work you discussed, I guess I’m interested in how much, how much people’s families are actually involved with the work through the sort of the social aspects of it?_

Well, curiously enough, the way she got involved, I mean I said we had a prefab and we used to get a lot of visitors coming to the establishment, particularly Americans, and I got involved with the political side of collaboration. There was a lot of collaboration on infrared between us and, well it was us and Canada mostly, it got broadened to Australia and New Zealand later on, but with me it was mostly with America and I would go across to the States and I would visit the defence labs. In fact, I’m trying to think about when it was. It was, yes, this was all at this time that I had forgotten this, but this was at the early stages I suppose of NATO when we were collaborating with the Germans and the French as well as the Americans and of course I was the British representative. It must have been sort of between the time I was twenty-five and twenty-eight or twenty-nine, and I was going across and defending my country and saying what needed to be said. That got quite political. It was interesting. I got on very well with the Germans.
There was a man called Dr Weihe and he was actually the American representative. He’d been snaffled and was over running the group at Fort Belvoir and was very interested in infrared imaging, so very interested in what I was doing. And we’d be going across and there were Germans as well present there and there were French and the interesting thing was, this was at the time of de Gaulle and we would be having discussions but the French had to present their case in French. Now that wasn’t a great hardship to me, it was more of a hardship I think to Werner and to the other Americans, but at the end he would stop and the interpreter would translate into English and the Frenchman would correct him. And sometimes there’d be a discussion going on between the two of them. He would say, ‘I said this, I know I said this, which translates into this’. And the interpreter would say, ‘No, no, no, no, no, the translation is this’. And he’d say, ‘How come the translation is this, the root comes from here, does it not?’ And we would all stare at each other and think, what a waste of time. This man speaks perfect English, better English than we do, and yet he has to deliver his thing in French, and he had to deliver it in French. But it meant that I saw quite a lot of Paris, which was quite nice. Then I think some of it, I have a feeling that at some stage we went to Brussels, can’t remember that. But anyway, they were okay, they were very interesting meetings but they had, this was... it was probably about ’58, I can’t place it exactly, about ’58, when Werner offered me a job to come across, he wanted to move on and he wanted me to come and manage the Fort Belvoir infrared laboratory. Well, we had nothing to keep us really. I think it probably was at the time when I hadn’t got promoted and I wasn’t that thrilled with the system. But anyway, he offered me the job and it was quite a good salary. We didn’t know much about Fort Belvoir but it was a bit isolated, it’s out in Virginia, and I’d been there a few times, but of course I didn’t have to live on the site – well, actually I could live on the site. Anyway, I said yes, I was interested. And then we went through at least two years of letters being exchanged, Werner saying everyone in Fort Belvoir is very happy with this, but of course there are problems with your nationality and the security clearance that you’d need, and the problem is this has never been done before, so it takes time. Okay. So I carried on with what I was doing and then after three months I get another letter saying well, we’ve overcome one more hurdle. We now, the Department of Defense is happy with this and we have clearance to go further forward. Fine. So we went further forward, another three months. Oh, and said, and by the way, your salary has been increased. I thought well good, good, my salary’s been increased. Well this went on for well over a year with letters coming saying, again, we’re one level further up and again your salary’s been increased. And then I got a letter from them saying, we’re at the commanding general and he says yes, but he says he’s not sure that he can actually give permission. He said, this is our problem, we have nobody saying no, but we can’t find
anyone who has the power to definitely say yes. So in the end we decided that it wasn’t going to happen. Then I got a letter from Ypsilanti, from – which is a strange little town where there was an infrared laboratory, University of Michigan I think, that was fully funded by defence, saying we understand there’s a problem but why don’t you come and join us. And this is a good salary and it’s a nice place. I actually went to Ypsilanti and looked around and I went back to my hotel and said, ‘This seems a quiet place’, to the barkeeper and he said, ‘Yes, yes, it is’. I said, ‘There seem to be a few people out but most of them don’t seem to be doing much, what’s the main activity?’ He said, ‘You’. I said, ‘What do mean, me?’ He said, ‘Well, you’re the most exciting thing that’s happened in this place this week, so everybody’s looking at you’. I said, ‘Oh’ and I thought this isn’t the place [laughing] for me, I mean it’s too quiet. It may be different now, but this was 1958, ’59 or something. And we decided we would start a family then, which is when Karen was born. It must have been earlier than I thought, because that was ’55, ’56. Anyway, Karen was born, and I think about two years later I got a letter from Werner saying it’s all right, everything is settled, you can come across now. But by then it had all vanished and I was on a different subject. But it was an intriguing idea that I could have run a lab. I visited several times and we got on pretty well, I mean we had lots of correspondence and suggestions of what was happening with thermal imaging and things.

Did you ever tell anybody in the UK about the fact you’d been offered this job in the States?

Oh yeah, sure. Yeah, didn’t keep secrets, yeah. Yeah, they knew. Well, I had to tell them because I had to get clearance to go, yeah. They weren’t bothered. [20:30] We were moving on in any case from infrared then. I said that Sutton had recruited Ian Ross, Dr Ross from the army labs, SRDE at Christchurch, to come and really set up solid state and he set up three groups, basically, and mine was at first not – can’t remember how exactly it got… maybe it didn’t, maybe we didn’t have three groups then. But I was given indium antimonide and Jimmy Edmond had been, he’d started some work on germanium with a new recruit we’d had, Arthur Cunnell, and they more or less, almost before I got out of the infrared area, they had sort of started this work. Once Jimmy had stopped work on his infrared vacuum tube he’d started work on germanium but it wasn’t getting anywhere and we had no material, they had to get their material from other places. So when Ian Ross came he thought we should work on two materials; a low energy gap material and a high energy gap material, and the low energy gap material was indium antimonide and the high energy gap material was gallium arsenide and I was looking after indium antimonide and Jimmy Edmond was looking after gallium arsenide with Arthur. And this was fine and I
realised quite early on, as did other people, that indium antimonide had the right energy gap for a photocell, but of course so did Malvern and Malvern started working on making photoconductive cells of indium antimonide. I started working generally on galvanomagnetic applications. All kinds of things you could do with indium antimonide and one of which was a new kind of photocell, which essentially was called the photoelectromagnetic effect. And a photoconductive cell – there are three kinds of cells you can make – one is the photoconductive cell, which basically is a change of resistance you get when photons of the right energy fall on a semiconductor and that essentially excites electrons and you get a change in the conductivity. The next thing you can do is, if you’re more advanced, is you can make a PN junction from the material and now when your photons fall on, if you’ve got it biased in reverse, then the electrons will affect the conductivity of the thing but they’ll change the voltage, so it’s a photovoltaic effect, you get a voltage, which again can be quite sensitive, but of course it means you’ve got to make a PN junction, which is a little bit more difficult, but it does give you some other advantages. Well, for one thing it doesn’t have to be biased, you can get a voltage directly from it, you could put a bias on, which in some cases is worth doing. The third one was not terribly well known and was based on the fact that if you put a magnetic field across a semiconductor the electrons and the holes travel, are diverted as they move in an electric field, they move essentially in a circle. And that means when you get an electron-hole pair in the material they get separated so that you can actually get a voltage developed and what’s called the photoelectromagnetic effect. And I was intrigued by this and showed that when you make this you can make a very small magnet with a high field, I obviously had to look at magnetism and things and develop the magnets – I’ve still got some of the pieces here actually. It’s quite a small magnet, the magnet was about, oh, two inches across. The gap was about a millimetre, you put the thing in, you have to make it in a slightly different way to a photoconductive cell, but I showed you could make a very sensitive photocell. Has the advantage there’s no bias. And in fact the cells that we were making were as sensitive, at least as sensitive as those that Malvern was making, which was intriguing. But it was clear that my cells were not really suitable to go in a missile because of the vibration effects. If you got vibration with a magnetic field you’ll get currents developed and the noise level will be very high. But of course it still meant that it could be used for commercial applications and Plessey were very interested in it as a device they could make and sell. But it meant that we were learning an awful lot about the physics of indium antimonide; how it was made, you need to make it pure and then you needed to dope it p-type and then I did a lot of work on the theory of p-type indium antimonide in particular and I did with one of the other staff who was quite senior, Oliver Simpson, who was the son of George Simpson who had been the
director of the Met Office, and Oliver was a very good physicist and we together did a fairly fundamental paper on a comparison of the different modes of operation of photocells. I forget… I don’t know if I’ll find this. [pause] Yeah, The Design of Single Crystal Infrared Photocells, that was ’59. That was fairly fundamental and was of course useful to the people now developing the cell for the missile, and it went into the next type of missile, as did the American ones because the Americans were also working on this and it was a much better photocell for missiles because it could pick up much cooler objects, could pick up the general aircraft’s frame rather than the jet itself. So that occupied people for quite some time. And then we were looking at the different applications of indium antimonide for its magnetic effects and it’s a very sensitive detector of magnetic fields. We made a compass which worked very well, it was a detector of metals. If you put it in a magnetic field gradient then it could detect very small motions, I mean of a few Angstrom units actually. It was very versatile. It also was a multiplier and generally had a lot of applications. [29:05] And then, as a result, with a colleague, who actually was a colleague in a different group, we invented the susceptibility meter. Now, I think - the colleague was Christopher Rose-Innes, who actually was an expert in superconductivity and he wasn’t working in our group in that way, he was working in a different group. Still in the solid state group because superconductivity is solids, but we had decided to write a book together on semiconductor III-V compounds, which was published, that was when I first got involved with Robert Maxwell, who was running Pergamon Press, and I suppose he contacted me first and said would I like to write a book in his series and I said, ‘I don’t know, I suppose so’. And then he told me what royalty I would be getting and I told Christopher and Christopher said, ‘Oh that seems very good’, I think it was twelve and a half per cent. And I said, ‘What do you mean, it’s very good?’ He said, ‘It’s very good’. I said, ‘I don’t think it’s very good, it’s his first offer’ I said, ‘I think we can get more than that’. So Christopher went away mumbling. And he came back the next day, he said, ‘I talked to my mother about this’. I said, ‘Oh really?’ He said, ‘Yes, and she says you’re quite right’. I said, ‘Oh, I’m quite right am I?’ I said, ‘Why?’ ‘She said never accept the first offer.’ So we wrote back to Maxwell and said that we’re not happy with your offer and we’ll only do it if you put your offer up. So he wrote back saying all right, I’ll increase the offer, I think to fifteen per cent. He said, ‘In view of the high quality of the book you are about to write’. And we thought, well how the hell does he know what the quality of the book is that we’re about to write. Actually I imagine that he was going to make this offer to us anyway, so yeah. I think I’d known Maxwell because I’d done some editing work, I was on the editorial advisory board of a journal. He was running, he ran a lot of journals, one was Infrared Physics I think, and I was on the editorial board so he knew me through that.
Never really thought of Robert Maxwell as a scientific publisher.

He was a scientific publisher. Pergamon Press was a very – still is – was a very scientific press. Actually, I’ll come back to Maxwell later on when we get on to displays, if I remember. So we wrote this book on III-V, which was interesting because I learnt quite a lot about III-Vs while I was writing it. And one of the things we did together is we invented this susceptibility meter. Now, the…

[32:15]

What is a susceptibility meter is my…

That’s what I’m going to…

Right, okay.

I’m going to tell you what a susceptibility meter is. The most sensitive way you have of measuring resistance is called a Wheatstone bridge. Now a Wheatstone Bridge consists of four resistances which are arranged as a quadrilateral, and that means there are four junctions and you connect a voltage source across two of them opposite each other, diagonally, and a detector of current, or voltage, across the other two. Have you got the picture?

Literally, doodling, yeah.

Right. So it’s a balanced system and the moment you throw anything off balance you get a large current throwing so you can detect when it is in balance. So if you have three standard resistors you immediately can measure a fourth. Or by adjusting the variable resistor you can see what an unknown resistor is. And of course, if you put oscillator as the source and a tuned amplifier as the detector, then you can measure very small changes in resistance. So you’ve got a very sensitive system. That’s for resistance. What we did was do the equivalent for magnetism. In other words, we had a magnet. We imagined having again four… metals, shall we say, that are magnetic across, and you’re measuring the magnetic properties. Now, the magnetic properties are rather different because what you can do is actually have gaps. You have magnetic materials like iron or cobalt or nickel as conductors of the magnetism, and then you have four gaps and the
gaps are places where if you put a material of some magnetic property, you will complete the circuit, the magnetic circuit. Now, of course you have to have a source of magneto-motive force the equivalent of your battery, but that of course is just a magnet and it can be a permanent magnet. So imagine you’ve got a permanent magnet and now you’ve got this quadrilateral that is mostly made of metal but in fact has four gaps in the magnetic circuit in which you’re going to put materials and see when you’re going to throw it off balance. But then you can get a bit more clever than that. You can say that the magnet itself is a magnetic circuit, so let us just take the magnet and put a contact in the middle of the magnet, more or less exactly in the middle, and just have two gaps. And now we will have a magnetic field detector in that arm which can be exactly what we’ve been working on because we’ve been doing it with indium antimonide. And now we can put, we can adjust the balance by putting a metal screw in one of the gaps and then we will see what happens when we put a material in the other gap. So what do you do, you put stainless steel in the other gap and immediately you find that everything is thrown completely off balance, so stainless steel is supposed to be non-magnetic, you’re detecting its departure from true non-magnetism. So you get more ambitious and before long you find you can measure the oxygen content of blood. It is an extremely sensitive system. Your problem is in fact extraneous magnetic fields and not moving things when you put your sample in the gap, and what you are measuring is the susceptibility of material. Now the standard method of measuring susceptibility is called the Gouy balance, and what you do is you actually measure the attractive force on the material with, there’s a large magnetic field and you actually weigh the change in the material when you put the magnetic field on. This is quite a large piece of equipment, it’s not very common and is very susceptible to errors, it is quite sensitive. What we had got was the first measured, first portable instrument for measuring susceptibility. Now, susceptibility is not something a lot of people would measure, but a few people are interested in measuring it. And we knew that this could be used, for instance, in looking at rocks and was the first time that geologists could actually measure the magnetism of the rocks that they dug up on site. [38:25] So we made this thing and then we patented it and it was passed to what was called the National Research Development Corporation, which is the way in which things were done then. If you could persuade the Admiralty to actually take out a patent on anything, which was not common, because the patent agents seemed to think it was their main duty to persuade people not to take out a patent. But I’d managed to get a lot of, a reasonable number of patents, I did more later on, but I got a few patents. And this was clearly good and immediately a company decided that they wanted to license it. Now, I had no say in the licensing, but NRDC decided that this company could have an exclusive licence provided they paid a minimum royalty of £100 a year. Now even
that long ago £100 a year was not much, right. Well, time went by and nothing had happened and I had arranged with this company, and with the full permission of the Civil Service, that I could consult with them on this device, which was not a defence device. So the system was quite happy that I could consult with them, and I forget what I got, it was probably £200 a year or something, it wasn't a fortune. But I was interested in doing it anyway and I knew how to make the bloody device, I'd made enough of them. And the company was called Electronic Instruments in Richmond, which I knew pretty well because they made some very good multi-range meters which we used and they also made PH meters, which are instruments for measuring the degree of acidity or alkalinity in chemicals. But nothing was happening. So I went down to see the managing director, who was a man called Paul Goudime, and he received me very politely and he showed me round the factory that was making his PH meters and then he drove me to his home in his beautiful Jaguar. I forget what colour it was, but it was a very nice Jaguar. And his home had a lovely garden that went down to the banks of the Thames, it was on the Thames somewhere near Maidenhead – may have been nearer than Maidenhead – but it wasn't that far, it was beautiful. And he sat me down afterwards with a drink and said, 'Well Cyril, I know why you've come. You want to know why we're not making the susceptibility meter'. I said, 'Well, I know you've got orders'. He said, 'Yes, we have eighty orders for it, mostly from universities who want to make it'. I said, 'So, what, why?' He said, 'Well,' he said, 'you came to the factory'. I said, 'Yes'. He said, 'You saw how busy we are', he said. 'Yes, yes, you're very busy.' He said, 'Now,' he said, 'if I take on the susceptibility meter I can't really put it in that factory. I've got to set up another factory which means I've got to take on a manager, and you've seen my car, what do you think of my car?' 'It's a beautiful car Paul.' He said, 'You're in my house, what do you think of my house?' I said, 'Lovely house'. He said, 'So, why should I? What am I going to get from it?' And I said, 'Well, I can understand that, that you don't want the complication of another factory and a manager and expanding, but why did you take on the licence?' And he said, 'As an insurance policy'. I said, 'What do you mean?' He said, 'Well' he said, 'I've got it. I've got it for twenty years'. He said, 'So, if anything happens in the year, in the world of PH meters and it goes out, I can wheel in the susceptibility meter. The orders may go by then but I'll get some new ones, so I can do it. So why should I do it?' So I went away frus... I didn't know what to say, I was just frustrated, I knew this was wrong but I didn't know quite what to do. Now, do you want to know the more stages in the story? It goes on for some time. Okay. Well, I was naturally irritated but there wasn't anything I could do about it. But some years later I was in the States at a place called Arthur D Little. Arthur D Little was a very good private laboratory that took orders and they were into liquefiers and things like that, very high reputation in the States.
And we were having an early lunch and the chap I was with was talking about inventions generally and things and what they did and I happened to mention, I said, ‘Well, I had a good invention but it’s never been developed’. And he said, ‘What’s that?’ so I told him this story. And he said, ‘This is ridiculous’. He said, ‘This is absolutely ridiculous’. He said, ‘Right’ he said, ‘What’s the time?’ he said, ‘Twelve thirty’. He said, ‘Right, stop what we’re eating, right, we’ll get the helicopter’. I think we were in Boston. He said, ‘We get the helicopter and we’ll go down to Wall Street and we’ll raise three million dollars, we’ll set up a joint company’ he said, ‘We’ll get the patent from NRDC and we will make it in the States’. He said, ‘What, what, you’re not jumping up and down with excitement’. He said, ‘I can get you three million dollars in an hour’. I said, ‘Oh’. He said, ‘What? Not enough? Okay. Two hours we’ll get five million dollars, that’s certainly enough’. I said, ‘I don’t know’. Hm. He said, ‘What’s wrong?’ I said, ‘I’m not the kind of person that gets in a helicopter and goes to Wall Street’. So he lost all patience with me. [45:50] Right, the next part of the story comes much later, much later, when I was in GEC and I was invited to lunch at The Economist because they invited industrial – they have a lunch once a week – and they invite, I was Director of Research of GEC and they invite people like that now and again, so I went there. And he said, ‘Well, you had a pretty successful life, would you like to tell us about disappointment’. And I said, ‘Well yes, I’ll tell you about a disappointment’. So I told The Economist about my disappointment. That week in The Economist appeared a cartoon and I phoned the editor and said, ‘I’m going to sue you’. He said, ‘What are suing us about?’ I said, ‘That cartoon’. He said, ‘The cartoon is a perfectly valid illustration of what you told us’. And what it showed was a helicopter with gold bags hanging from it and what was obviously meant to be me hanging from the skis underneath it. And I said, ‘It’s the way you depicted me’. I said, ‘It’s embarrassing and it is calculated to denigrate me in the eyes of my fellow men’. And he said, ‘Denigrate you?’ he said, ‘Why?’ I said, ‘Look at the hair’. I said, ‘Everyone knows I have lots of hair and you’ve shown me with just one lock of hair coming out from my head, that’s ridiculous’. So we parted as friends. Now, what did that teach me? It taught me, do not have exclusive licences. If you have an exclusive licence it puts you in the hands of the licensee and that carried right the way through to later on in the story, actually sort of ten years or more – no – fifteen years later when I did have to think about licensing and people sort of said, why are you doing this? I said, ‘Because of the susceptibility meter’. And they said, ‘What’s the susceptibility meter?’ I said, ‘Never mind, it takes too long to explain, but I can assure you I will never agree to an exclusive licence again, not completely exclusive. Maybe exclusive for a year, but not completely exclusive’. 
Did it ever get built?

No. It’s still not built, still get people ask about it. Yeah. And it’s still available. Oh well, I mean the patent’s expired a long time ago, yeah. And now you could make a much better one, actually. And as far as I know, nobody’s got a good susceptibility meter.

Where did the idea first come from?

Oh, I think it was, it was… susceptibility is something that people who work on superconductivity think about. That comes much later. If I ever do talk about high temperature superconductors – who knows, I don’t often do that – but one of the methods of checking whether you’ve got a superconductor is to measure its susceptibility. It’s much easier to do that than to measure its conductivity. You can’t always tell that, but anyway, so Christopher was very up with measuring susceptibility and will have mentioned it to me and I was very up with magnetic circuits and… The reason why the universities wanted it was not to measure susceptibility but to explain magnetic circuits, because that shows you, the susceptibility meter by its analogue with the Wheatstone bridge, actually shows them the reality of a magnetic circuit and it’s not easy to show that in any other way. So that’s why they wanted it. And it was a cheap instrument anyway. It was pretty easy to make, there was nothing in it.

I was wondering if we could say a little more about patenting policy while you worked at the MoD. Did you get many other things patented?

I’m not… I could actually look up my patents. I patented much more later on. We were conscious of patents but not of their value. We now know that people are much more interested in exploiting something if they think they’ve got some rights over it. They do not like the idea that they will start making something and when it’s a success somebody else will copy them. May not copy them exactly but they’ll copy the field it’s in and really build on your efforts, which is irritating. So, that’s the first thing that you have in patents, that it’s protection. The next thing of course is the money that you might make from it as a company. The company I work for now essentially makes something but they don’t reckon they’re going to make really much profit out of making it, what they’ll do is they’ll license the actual devices, instruments, the applications and they’ll make the money from the licensing of it. And this can be very lucrative, but you have
to have patent control and though we’re a small company we have over a hundred patents. I, I’ve been very conscious of patents and have passed this on so much that my group at Malvern, when they met for coffee, would talk about what they’re doing and if somebody said, oh I’ve discovered this, the question that was always put to them immediately was, ‘Have you patented it?’ Whereas other groups would say, ‘Have you published it?’ The group knew that the first idea was that you patented it and at one stage our group of about, I suppose it built up to twenty, twenty-five people, they were taking out half of the patents of the whole Ministry of Defence, yeah. We didn’t make the hundred million quid by accident, you know, it was directed and that has lived with all of them when they’ve gone somewhere else they know that patents are very important and I learnt quite a bit about patents. Okay, since you raised patents, let me go ahead and talk about Siemens and patents on III-V compounds. We’ve gone into III-V compounds and the initial work on III-V compounds was certainly done by Siemens, a man called Heinrich Welker, had come from Paris and went to Siemens in Erlangen and had really thought hard about semiconductors and decided that compounds of the third and fifth group were the way forward. And Siemens had got extensive patent cover, which of course was a bit of a problem and later on when we had got applications of things, Siemens applied for an extension of their patent cover on the grounds that they had not exploited it adequately. Now, you can get an extension of patents if you can show that there are good reasons why you haven’t exploited it, but you have to demonstrate due diligence. And this was going to be very awkward for us and for a lot of other people, and there were people in the UK who were very concerned.

*Is this us still the group at Baldock?*

No, this is now moving on. It did affect Baldock, but in fact I’m pretty certain this must have been while I was at Malvern. I’d have to think about when they… it’ll be twenty years after the original patents. It almost certainly was, it was probably near the transition of me going from Baldock to Malvern. I think it was, I’m not sure. It could have been… well, whenever it was, I think it may have been the Admiralty were still involved, because they had most of the patents and there were other people coming in, Ferranti and other people. Anyway, the Admiralty asked if I would consult with them on this, I mean not being paid, because I was a civil servant, but I would work with them on this, and there was someone I knew well who was paid, I was furious because he was paid but I was doing more than he was. And they had 330 patents or something like that, that they were putting forward. So I read them, I read 330 patents and I analysed them and I said there are, I think there were eighty patents on indium antimonide and galvanomagnetic
applications, which I said there is no question that those patents are valid, but on the other hand Siemens is exploiting them now, they are making hall effect devices and magnetic sensors and things, they have, they’re more or less the world leaders in this, there’s no reason why they’re not getting a return on these patents, they are exploiting it. I said then, there are at least a hundred patents on silicon, where the claim says, the first claim is I’ll make a thing of silicon, a device whereby the material is any compound of the third and fifth groups. I said, ‘They’re rubbish because you’re not going to make them in gallium arsenide anyway, or anything else, you’re going to make them in silicon. You can’t make them, in many cases you can’t make them’. And then there’s this intermediate ones where we actually had to talk to, I suppose it was a QC, and I said, ‘There’s this patent here that says any device made from any combination of materials in the third and fifth groups of the periodic table’. He said, ‘Yes’. I said, ‘Isn’t that a bit general?’ He said, ‘Maybe, yes’. And I said, ‘What guidance does it give you?’ He said, ‘None’. I said, ‘But you must get guidance from a patent’. He said, ‘Yes, you must’. I said, ‘Gallium arsenide doorstops?’ He said, ‘Oh yes, they’d be covered wouldn’t they?’ So he said, ‘I think that is a bit thin’. I said, ‘Then they are claiming that there’s a patent here on the semiconductor laser and on the transferred electron device’. And he said, ‘Yes, I think they are claiming that’. I said, ‘Can you patent a device before it’s been invented?’ And he said, ‘Hm, hm, I don’t know’. Actually, I don’t think this was a QC, I think this was a patent solicitor. No, he was a QC, he was a QC. Because I remember now what he said. He said, ‘Mm, that’s a difficult question’. He said, ‘I think that would have to be decided by a judge’. I said, ‘You really mean that you can patent something before it’s been invented?’ He said, ‘No, I didn’t say that’. I said, ‘What are you saying then?’ He said, ‘Hm, I think probably no, but mm, I suspect a judge would say no’. So we went through the patents in that way. Anyway, I suppose it was a month later, the patent people at the Admiralty rang me up and said, ‘Oh, you’ll be pleased to hear that Siemens is withdrawing their claim. We’ve sent them your analysis and they’re withdrawing their claim for an extension’. I said, ‘Oh good’ I said, ‘And what’s happening about costs?’ He said, ‘Well, we’ve agreed that we’ll each carry our own legal costs’. I said, ‘That’s ridiculous’, I said, ‘They should pay our costs’. He said, ‘You are a hard man aren’t you?’ I said, ‘Well this has been a complete waste of time as far as we’re concerned’. This was completely unreasonable on their part, they’ve ignored gallium arsenide for years and now other people have made all the running and they want to benefit from it. He said, ‘Well maybe, but still, it’s probably best’. And that’s how it was left. But of course it gave me an interest in patents, which I have maintained to this day and I’m still having patents in my name.
What’s it like dealing with patent agents earlier on in your career?

Well, as I said, the first ones were really disappointing in that I think their main aim was to persuade you not to take out a patent because it gave them trouble. When I moved and was at Malvern they were a delight, the people I worked with, and I would say they’re still friends. Bob Beckham, excellent man, still is sort of consulting for them, I think he’s retired now. Excellent. Always listened carefully, improved what you had to say. The people I deal with now through the company I’m a non-exec of are very good, they give advice. I don’t always agree with people, but that doesn’t mean to say they’re not right. There’s lots of opinions on patents as to what you can cover and what you can’t cover. Some of the comments I’ve had on patents that have been put up are very helpful, others I don’t agree with, but that’s life. But in general I would have said that patent agents now are far better than they used to be and they’re very conscious of the power of patents now more. Patents, I think the point was that patents were used more by the Civil Service as protection earlier, they weren’t thought of as ways in which they could make money. Later on they became more conscious of it, there are quite a few patents that have made quite a bit of money for the system. The, our patents on liquid crystals are the only ones that really the Ministry of Defence has made money from.

What made Bob Beckham a good patent agent?

His motivation, his activity, his energy and his general assumption that you knew what you were talking about, so that he would improve what you had done from his own knowledge so that he could protect what you were inventing. But he wouldn’t try and second guess on the importance of the patent, because that would be impossible for an agent to do really, in the sense he has to cover so many fields that he can’t really go into marketing.

What sort of interaction do you actually have with someone like Bob Beckham?

Oh, it would be second-hand quite a lot, in that in Malvern you’ve got your own patent section in the laboratory and you would know the people there very well and they would help you in drawing up the patent in the sense of seeing what weaknesses there were in what you were thinking about and they would be doing the form of the patent. You wouldn’t be doing the claims. You would be doing the background, they would rely on you to cover the background
and you ought to do your own search. The scenario has changed a lot with the web. When I was taking out a number of my patents the only search you could really do was to go up to London to the Patent Office and there you could consult very big books, they were books about two feet high which you’d take down from large shelves and try not to get too much dust on you, and then you’d open them to read them, this was Chancery Lane or somewhere like that, and then you’d get copies made of the things. And it was a labour of love in the sense that you had to love it otherwise you wouldn’t do it. It was quite time consuming. It was obviously easier – I don’t remember doing that when I was at Malvern, I suspect that the search system by then had got much better and the patent agents… you see, the difference was, in Baldock you were relying on a patent agent in London who was a patent agent for the Admiralty as a whole, or be one of a group of patent agents working for the Admiralty. In Malvern as far as I remember, we had two patent agents actually in the establishment, which was a great simplification and there was a senior one and a junior one and they both were very efficient and active so it worked pretty well. But then they would put you in touch with Bob Beckham who was at headquarters, but he would come down and see you and he was the person who really made the decisions. Right, have you finished your background questions – do you want to get on to the next thing?

*Wondering, how did the work on semiconductors actually go?*

On which semiconductors?

[1:06:45]

*The III-V, you mentioned that the groups were sort of split into three, well there were three different groups under…*

Yeah, now we get to 1959, roughly. Actually, I’d got my doctorate, I was pretty happy, I was doing a lot of travelling and things and people, I sort of was winding down on infrared, but was winding up on semiconductors.

*Shall I unplug you a second?*

[end of Track 9]
Yeah, I was beginning to get known. I’d got the book which was now published and people were very interested in it and obviously Christopher and I now knew a lot more about semiconductors than we’d done at the beginning. And the indium antimonide work was almost coming to a natural end in that we knew how to make it, we’d done the physics of it, I’d got some publications on it, I did one on, quite a long one on the properties. When was that? [pause] That was ’58, that’s right. Well, you see, if you look, again, I had… in ’58 I was finishing with what I’d got on, I’d written up the work on, some of the work on image converters and now I’d got one, two, three, four, five – five publications in ’58, five in ’59, so all of it was very productive and people were pretty happy. I’m not sure that Sutton was that happy because there weren’t any defence applications, or at least many that we could find. They were interested in effects in magnetic fields but we couldn’t find that you could use those for defence applications much that were a possibility. [01:48] But then Jimmy Edmond and Arthur Cunnell discovered this idea that they’d had enough of gallium arsenide. It was too difficult a material, they weren’t able to make good things, it was driving them both mad and they wanted to do something else. And I don’t know what happened to Jimmy, I think Arthur basically went to Farnborough to a different establishment, he wanted to leave and Ian Ross said, would I like to take on gallium arsenide. I said no, but I suppose I’d better, someone’s got to. So it was generally thought to be pretty near a dead end. It was a very difficult material. The way in which you made it was to heat up the gallium and the arsenic together – this was early days – you heat up gallium and arsenic together, you put them in a quartz tube which you evacuated, sealed it up, put it in a furnace and retired to a safe distance, and when it got up to the temperature you hoped at which gallium and arsenide are going to react, it would then cool down, but as often as not when it did that it exploded. And then you went into the hut where you put it outside and you picked the bits of gallium arsenide out from the wreckage. There were improvements that people discovered with more complicated furnaces, but it wasn’t an easy material to make.

What does it actually look like?

Well, it looks a bit like most semiconductors do; sort of vaguely metallic, slightly brownish, sort of – it’s not transparent, I mean it’s completely opaque, looks like a bit of rock actually. Don’t know if I’ve got any, might have. It just looks like a metallic slice. All semiconductors that aren’t visible ones look pretty much the same, shiny. But in fact, when I took over I discovered
that Jimmy and Arthur had more or less solved most of the problems. There were things still to
be done but we knew much more about how to make it and how to purify it. It wasn’t in a good
state, but it wasn’t that bad. It was obviously much worse than indium antimonide, but they had
made a hell of a lot of progress and I was able to build on their achievements. But I did realise
that this was a big job and there was no question that we were in competition. Most people now
thought that, well, most people now, some people in authority in the various countries thought
that gallium arsenide was worth working on and the Americans were placing quite large contracts
with the bigger companies, particularly RCA and Texas Instruments and Lincoln Labs, that was
part of MIT, as well as some others. And I realised that if we were going to do this we needed
help. Now, I knew through CVD that I could place contracts with industry, but I also knew that
industry would be very conscious of the risks of doing this, that yes, they’d be paid to do it but
they’d be using staff that they might well think would be better employed on things that were not
quite so difficult. I invented a target which I put to them, which I called the Red Hot Transistor.
This was a time, remember, that people were still beginning to think about silicon, the problems
of silicon. It wasn’t – this was ’59 and at that stage silicon was seven times as expensive as
germanium and it was responsible for about six per cent of the world’s supply of devices. It was
a difficult material to make. So I said we’ll make a red hot transistor which will outperform
silicon and one of the things we knew was that the mobility in gallium arsenide was ten times, or
should be in theory, ten times that of silicon, you can work these things out.

Mobility?

The speed with which electrons move in the material. Remember, I gave you a figure of seventy-
odd thousand for indium antimonide, 1,000 for silicon, 3,000 for germanium. The figure for the
gallium arsenide was 10,000, a little bit less than that, but it should be about 10,000. So you’d
make a higher frequency transistor that would work at a higher temperature, what more could you
want? Well, you might want to make it. [07:55] And I decided that the only way in which we
could actually make progress here was getting everybody to work together and I invented the
concept of an industrial consortium and I wrote the rules, which were that nobody has secrets,
everybody tells everyone else what they are doing. The programme is decided, though in
principle I am responsible for it because I am the monitor, but the programme will be decided
collectively, everyone who wants to patent will tell everyone else first of all what they want to
patent and get agreement that it is theirs, and in fact we will work as one large group. Now, this
might seem to you very sensible, but at that time they didn’t even know the people in the other
companies, they didn’t know their names. They couldn’t ring them up to collaborate, they didn’t have any telephone numbers there. And CVD was very uncertain, they said, well you’ll never get the bosses to agree to this. I said, ‘Well, we can try’. And they said well, we don’t want anything to do with this because it involves commercial security too much. As far as we’re concerned we will place the contracts and you will monitor them. How you want to handle them is up to you and we don’t want to know. As far as we’re concerned if you get it established it will be called Hilsum’s Consortium and if anyone asks us about it we’ll say it’s Hilsum’s Consortium, we don’t know about it. Right. So, I started off with Plessey where I knew the people pretty well. I had a friendship going with Derek Roberts, which still exists, and he later moved to GEC and became deputy managing director and in fact recruited me to GEC. I knew him very well from the work we had been doing on indium antimonide and indium arsenide where they’d made photocells and we spent time in Brussels together at the World Fair, and I was pretty certain that he would agree, and he did, more or less straightaway and said yes, no problem, we will accept those rules. I then went to Marconi, which was beyond Chelmsford, then to their lab, the one that was making essentially silicon, or beginning to make silicon, mostly germanium. Who else did I get? Well, I got Mullard’s, though that was later, Philips Lab. There’s one lab I’ve forgotten, but never mind. And we all agreed to work together and we apportioned responsibilities and it began to work. We gradually purified the material, gradually purified the material and we were – oh, STL at Harlow was the other lab – and together we were able to compete with America. Separately we wouldn’t have been able to, but we were operating as one body and… it wasn’t that much later that we learnt how to purify the material. Malvern actually came in a bit later after I’d joined them with a way of growing the crystals, but I’ll get to that later on. But essentially we had organised it so that we were collaborating in a consortium. And I will say that that possibly, that establishment, the way it’s done is probably the biggest contribution I made, I have made because that was adopted later on by many people and is the foundation actually in the way the European Commission works now with their collaborative programmes. Collaborative programmes were unknown before. And of course when I moved, which we’ll come to, CVD then changed the name of the consortium, it became the CVD Gallium Arsenide Consortium, not Hilsum’s Consortium.

[13:05]

I was interested in the way that, you know, CVD sort of, you know, said oh this is down to you, you know, we want nothing to do with it, we’ll let you get on with it. How was that sort of information actually told to you?
I wasn’t bothered.

*Oh, I just sort of…*

Didn’t worry me. They said we cannot take official responsibility for this because of commercial security. We cannot say that we are persuading the companies to give up their commercial rights in this way. It would have to be done centrally through the Civil Service, if you want to do it with the companies on your contracts, that’s fine, that’s your own responsibility, but it can’t be done officially.

*I was just wondering about how they actually told you that? You know, was it sort of an open committee meeting or is this sort of a quiet drink down the pub where they say get on with it?*

Oh, it would be done as a committee meeting, I don’t think… I wasn’t chairman of the committee then. I was a member of the committee, later I was chairman of the committees. But no, it would have been done through the secretary of the committee, would have said look, don’t tell us, because if you tell us we’ve got to do something about it, but as far as I’m concerned you handle it any way you like. You’re the monitor of these contracts, we’re very happy with that, and they’ll do individual reports in the normal way and the fact that they will circulate those reports to each other before so that it’s approved by everybody is up to them and you, it’s none of our business. But we will get a report from each company on what they’ve done and we will pay them their money as though it’s an individual contract. So everyone was happy. And later on there was a consortium on surface acoustic waves, the liquid crystal work was organised as a consortium, we actually had a consortium through the DTI, which was called JOERS – Joint Optoelectronic Research Scheme – which Derek Roberts set up and said it will be as a consortium. And in fact there was big trouble there at one stage when one of the people in the consortium claimed that they had invented something in their spare time when they weren’t working for the consortium. Said you cannot do that. But that’s the system now that is used quite often, but if you actually think about it, companies are supposed to be set up to make money for the shareholders, they’re not supposed to give results to other people. And in fact later on, as I will repeat, when we made the first microwave oscillators, it was marketed first by Philips-Mullard to a design which Malvern had created using a technology made by Plessey with a microwave structure designed by STL at Harlow. Can’t think what Marconi had to do. That was the device and it came out and
was very successful. A month later – I’m not sure which came next – I think it was STL came out a month later and Plessey came out a month afterwards. Three all making the identical device with different labels on. And one thing that irritated me was all at the same price too. And they all were fifty quid and I knew it cost them less than ten to make them. They said well, it’s not actually this, they pointed out that it’s the same price as the klystron and you don’t need a power supply, just works off a few volts. But we will come to that one later because that is actually quite complicated.

*What were industry’s reactions to you setting up this consortium? What did people…*

Oh, the bosses didn’t want to know. Again, they took the same view as CVD did. They said we are not having this conversation. They said we do not want this in writing, how you run the contracts is your business. If you really feel that we will gain by it, by getting access to what the other people are doing then we’re happy, if you believe that they’re going to obey the rules. I said, I’ll make sure they obey the rules, I said, but it means that you have two people working on it, that you have full access to the work of at least ten people plus the group as it is at Baldock, which is another ten people. And they said, sounds a good deal to us but we don’t want it in writing. And that was common of all of them, basically. They said you go ahead and all power to your elbow and we hope it works. [18:10] And it did, obviously work. I mean, but there was no other way in which it could have been done. And in fact the Americans admitted that in some of the things they were trying to do, where they were working separately, all of them were working separately on things, and they said the group that worries us is Cyril Hilsum’s group, by which they meant Cyril Hilsum’s Consortium. And it was obviously working because a few years afterwards Texas Instruments asked to join the consortium, and that was difficult, that one was difficult. ‘Cos they were so powerful, I mean they must have, they had more people working on gallium arsenide paid for by the Department of Defense and also some private money going in. They were a very good laboratory. There was no logical reason why we should refuse, but… I didn’t want it, I didn’t want them. I had to put it to the consortium and they I think were like me, they would say what a good idea it was, but… And we never said no, but we never said yes.

*Why the reluctance?*

Well, we thought they’d swamp us and we didn’t think we’d get the credit for the things we did, I suppose. We never actually analysed it as to why, it was one of these instinctive things that
you... it's like you meet someone and you shake hands with them and think, mm, I don't really want to have a drink with this chap. I don't know, I mean we had nothing against them, they were a good crowd and they were doing lots of things. In fact they were the people who made the most progress on silicon first of all, and they certainly did some good things on gallium arsenide. But they weren't quite as good as RCA and it wasn't as though we didn't know what the people were doing, because we were in a slightly privileged position because I got all the reports through DOD, which actually was slightly awkward as people understood, because I couldn't actually broadcast what was going on on the American contracts, though I knew. But there was a lot of goodwill and to some extent it was goodwill because of the problems. You see, I would go across, this came a bit later, it came and well, it was while I was at Baldock and as well as when I was in Malvern, that I would visit America and go round and the chief scientist, whoever was showing me round, saying well I know that you're interested in gallium arsenide but we don't do anything on gallium arsenide, but I want to talk about some of the other things we're doing with you. And I'd say fine, fine. And then, at a quiet moment somebody would pull me aside and say, you know we are working on gallium arsenide but he doesn't know. Try and find a moment to break away and we'll show you what we're doing because we would like to talk to you about it. And they'd have a small group of people working on gallium arsenide that the boss didn't know. This was a black [programme] And that happened in a number of labs where the scientists wanted to work on the thing and by then they actually could get material in, they didn't have to make it themselves, they could buy it and do various experiments on the thing and it was then under control.

*Why do they want your opinion in particular, and on what?*

Oh, but they knew that I was, I had written articles on gallium arsenide by then and I'd got, the book was out and my written articles.

*Any occasions you remember in particular?*

Oh I wouldn't, I don't want to get anyone in trouble.

*Well, you know, I guess we don't have to say what the company is, but an idea of what happened, might be interesting.*
Oh, it wasn’t unusual actually for this to happen. I mean I would be invited to the company because of my general appearance on semiconductors, I mean I was doing other things as well as gallium arsenide and I was giving invited talks generally on III-V compounds and things. And would talk about the physics of things that might be applying to gallium arsenide. I gave an invited talk in 1964 at the Paris conference on the physics of semiconductors, which I think was, yeah, ‘Band Structure, Effective Charge and Scattering Mechanisms in III-V Compounds’. I’d got all the galvanomagnetic things, I’d got the photocells in indium antimonide, so it was a fair amount I had that I could talk about to people. So it was quite reasonable that I would visit the places as a general physicist. And of course I knew the scene in the UK pretty well, so I had no problem with visiting places and it was… I can remember, there was a thing called the Device Research Conference that we went to. The Americans were pretty open. This Device Research Conference was, you could only go to by invitation and the main companies all went there and would discuss progress in various things, including silicon, germanium, compound semiconductors and of course things like gallium arsenide. And you would get to know the crowd there. Now the rules of that were quite specific. You could not take recordings or pictures and - but you could write down notes and the bigger companies, each evening would all get together where the people would compare their notes and write them down, and you were not allowed to report on it. You could not actually write it up and in fact one Englishman did get invited to the conference and he wrote it up, an academic, as a consultant charging for it and I was told that I had to talk to him and get his report withdrawn, otherwise no Englishman would ever get invited again. I summoned this gentleman and said he had a clear choice. He could either withdraw the report or he could accept that he would never get any government funding from any source whatsoever after this. And what is more, he might lose his academic contracts because we could point to the fact that he had broken faith. He agreed to withdraw his report and all was sweetness and light again. But they were quite specific, that this was a privilege, and it was, that you could actually go there and hear what was going on before it was published. And we of course actually gave our own presentations too before we published them. I mean we joined in and it was friendly. And at one of these, Bob Rediker from the Lincoln Lab at MIT which had done a lot of work on gallium arsenide and continued to do it, formed what he called the Anti-Silicon Society and it’s no accident that the acronym is ASS. And we had founder membership and I can proudly say I’m a founder member of the Anti-Silicon Society.

*I think we’re approaching the end of today, but I thought it might be*...
We are approaching the end of the first part of gallium arsenide before we start coming into troubled waters.

*I thought it might be a good time to perhaps, [27:25] as a way of sort of, I guess, summing up to some extent your earlier career as we’re moving on, I’m thinking what’s actually interesting you about all the work we’ve discussed today?

I think it’s the, always what interests me is the personal nature of things. Well, what interests me is how people can benefit from being in the right place at the right time in a way that is not apparent to them then, but when you look back on it you can see if I hadn’t been there, then I wouldn’t have done that. And how some things that you think have been really bad have later, you realised, helped you. I mean the susceptibility meter is one where you could moan about it and say that was the best thing I ever did and look what happened. And in fact I know that because of what I went through then I was able to make a success later on which I almost certainly would not have done because it wasn’t the advice I was being given, and I said no, I know what I’m doing on this and we will do it this way, because I am not going to go wrong twice. And it’s things like that that really have helped me a lot. And some common sense, some logic that came through where in fact you could see that, I mean it was the right way to go, the consortium. The only way we were going to make progress was by getting a large group working on it and there wasn’t a large group because people weren’t prepared to risk large groups, so then you said well, logically in your mind you say well, what are they prepared to risk, and the answer was two people. And you said okay, five times two is ten people, that makes a good group, so we’ll bring together five groups and work as one. So it was all logical in that way. Yeah.
That’s all right, I can get you started.

*I guess we’re about halfway, well part way through gallium arsenide aren’t we?*

Yes, well I mentioned that I was lucky, I’d inherited a group really because Jimmy Edmond and Arthur Cunnell had had enough and looking back on that, they had actually been working on it for about six years, because their first paper was about 1954, and in 1959 they published a pretty conclusive statement of what they had accomplished, which was back breaking and had got them to a certain stage, which was quite remarkable really, it was well up to world state of the art and they’d learnt how to make the material, how to dope it, how to make simple devices from it. They couldn’t make anything complicated and the purity of the material was still limited, but essentially they had laid all the foundations, so I’m really not exaggerating or being modest when I say that I inherited a working project, something which they had done all the ground work and they got no credit for it at all as far as I can see, they were never mentioned in all of the literature. I came in and everything seemed pretty straightforward, it was fairly logical. So I don’t think I’m exaggerating when I say I just was lucky to come in at that stage. They gave up, they were worn out, they did other things. So, I now was handed gallium arsenide and it was fairly obvious that what I had to do was to organise the contracts, set ourselves up as being equivalent in the world to all of the strengths going on, particularly in the US. It was clear that although Siemens had actually started the III-V compound work, they had also given up on gallium arsenide and indium phosphide and the higher temperature compounds, those with a bigger energy gap which would function in the visible and near infrared and would be candidates for semiconductor devices other than the galvanomagnetic applications, the galvanomagnetic applications they were pursuing and that was okay. But they really weren’t doing anything on what you might call the alternatives to silicon, whereas in the States there was considerable effort on compounds going on, I have said this, but perhaps I haven’t emphasised that there was a different way of doing device research in those days to what it is today. Essentially almost all the big players were industrial or government laboratories, in both the US and the UK. The work was funded in the UK by, well, it was essentially by, then it probably was called the Ministry of Aviation or Aviation Supply or various names, we hadn’t got a Ministry of Defence by then. In the US it was funded by the Department of Defense. But the main logic was that the government would support the risky part of the research programme where there were many uncertainties. The companies might put a bit
in, but in general the government would support it. And then when it came to development there would be a slight withdrawal and of course when it came to production, unless the government wanted to order actually devices or components, then industry would take over. And that seemed to work pretty well, but of course it meant that the government had to function in a knowledgeable way and ours certainly did, we felt that we had to know as much about the subject as industry did, that we couldn’t place a contract with a company and leave it to them to actually decide exactly what should be done without us having at least a discussion on the subject, and you can only have a discussion if both parties understand the subject. So we were quite prominent in the field and that applied at this stage, both to us at Baldock and to the people at Malvern. [05:00] Now, we were trying hard to find an application for gallium arsenide. The Ministry of Defence – no, I can’t say the Ministry of Defence – the Ministry of Aviation was patient and they would leave it to us and to Malvern to do some fundamental research both on materials and on the physics because they felt something would come from it. But we applied our own pressures and we wanted something to come from it and it’s not easy when you’re dealing with a difficult material over which you have very little control, but we were anxious to understand the physics of the material so that we could make devices which people could be interested in, as were of course all of the other participants, I mean they weren’t working for companies that were philanthropic, though the work was being paid for, companies expected something more from their research scientists than just fundamental research and how to make the material. So all of us were doing that. I’ve mentioned that we were trying to make a red hot transistor, but we knew that was a long way off, though we each had defined parts of play in this. [06:25] The first interesting thing that happened was that one of the American laboratories discovered that if you made a junction of gallium arsenide that was heavily doped – this was easy because it was very difficult for us to do light doping.

What’s doping, sorry?

Doping is adding impurities. If you take a pure semiconductor like silicon or germanium or gallium arsenide, if you have no other atoms present in it then it will be an insulator. You put an impurity in and you know the impurity. I did actually mention this earlier, if you put in something from the second group then you make holes, if you put something in from the sixth group then you give extra electrons. So, this was relatively easy in doping, but of course it’s better if you start off without any impurities and only put those in that you want to put in and in fact in general when you made gallium arsenide you already had $10^{17}$ impurities per cc and that
you did not want, you would like to be down in the $10^{15}$ level, but it took some time before we could do that, and we’ll get to that later. But now, the lab in Princeton, the Radio Corporation of America lab, discovered that if you made a junction that was heavily doped and you applied it in the forward direction, that is the direction of the diode that has low resistance, the other direction has high resistance, then you would be injecting electrons and holes into the middle of the device. There they would cancel each other out and when they did that, they would emit a photon, a photon of light. But with gallium arsenide it’s infrared light. And they showed that if you actually did that to a PN junction of gallium arsenide you got a burst of light in the infrared, and it isn’t obvious how you could use that. Now we’re used to LEDs, but most people would not be interested in an LED that they couldn’t see, but we were interested in an LED you couldn’t see because we knew we could detect it. We could detect this light very easily, in fact we could detect it with a silicon photocell, which is the same PN junction but isn’t doped as heavily and now when light falls on the PN junction you get the reverse effect – the light then breaks up its energy into giving you an electron and a hole and of course these then can be made to go in opposite directions in the material and it gives you a current so you’ve got a photocell. So this was a combination of an emitter of infrared radiation and a detector, which starts making you think because of course light can go a long distance and you can actually have a light source in one place and detect it in another place. People had done that for many years, with lamps and photocells – not the kind of silicon photocells – but here you could do it in a much more controlled and efficient way because the actual production of light was very efficient. You got a number of photons out, the number of photons you got out for every electron that you passed through your circuit was very high, the efficiency could be some ten, twenty, thirty per cent, which was very good when you consider that an ordinary tungsten filament lamp available there, the actual amount of light you get out is about four per cent, most of the energy goes in heat. This was cold light, there was very little heat. And this was one way in which you could distinguish the III-V compounds and particularly the materials like gallium arsenide, from silicon and germanium, because people have been trying to do this in silicon and germanium ever since, but the fundamental nature of the materials – and we may get on to that later on - meant that with silicon and germanium, if you put a lot of current through you got a lot of heat, but not much light, bit like politicians. But if you actually do it with III-V compounds, the way in which the energy levels within the material are constructed means that you are favoured to actually convert the current into light rather than heat. And this of course was a big relief to us because it was something that you could show from the physics, but it hadn’t really been shown in devices before then. So this opened up an area in which III-V compounds could be used and used to
considerable advantage, but of course in the infrared we had to consider exactly how we were going to use it. We made these LEDs and could see them actually working with our own image converters and with our photocells. [12:15] And then we had a request from India and it was a very strange request, it was from the government communications headquarters who said they had a real problem with tape readers in the Far East. Now tape readers were a way of putting information into, I suppose you could call them very simple computers, but they were too simple for us to really call them that then. But they were a tape that had a number of holes in them, as I recollect there were probably either five or ten holes across it and when you exposed that to a light beam and ran the tape through, you got a digital signal effectively coming out each time there was a hole, and this was the first way in which information was put into computers, we had punched cards called Hollerith cards which were used for that. It was pretty cumbersome to do it, but it was the way in which information was fed into the first computers and this was the way in which it was fed into the tape readers which they were using in the embassies for their information transfer, that of course was a continuous tape which was run through so you could imagine you’ve got a complex signal of ones and noughts coming through. The problem they had was that the tapes were handled and when the tapes were handled they would become translucent and so the actual difference between a hole and a piece of tape was not very large and we were asked if we could do anything about it and we realised that with the infrared emitting diodes, one virtue of them was a very small and controlled area. You could design this in any shape you liked, depending on the way you put the electrode down, and it was in one position. If you were using an ordinary lamp as they were, a tungsten filament bulb, a small one albeit, you didn’t know exactly where the filament was. I mean it was roughly in one place but of course it spread over quite an area. We, we had a point source. That of course meant that you could have a very simple lens system which focussed the infrared radiation coming out from our LED on to the place where the hole should be. Well, we made a very simple tape reader, in fact I did it with one of my colleagues and we supplied it to the government communications headquarters and we showed that it not only had a difference when the tape was translucent and handled, you could actually flood the tape with oil and it still worked. They were amazed, very pleased with us. We were pleased with ourselves of course because we’d actually made something and it was used in the embassies in the Far East. So gallium arsenide had actually done something. On the other hand we couldn’t pretend that this justified the number of people we had working there. So we carried on, essentially improving our control over making the material and doing all the things that you do in a pretty standard way to get purer material so that we could then dope it. At the same time we were doing research, fundamental research, on the nature of gallium arsenide
and of the other III-V compounds.

[16:29]

I’ve got a few questions that have occurred to me over the course of this. One of them you touched on ever so slightly a moment ago, which was one little device couldn’t justify the existence of this big group working on something and you sort of mentioned earlier on that the Ministry of Aircraft Production, or whoever it was, were always quite happy to just let you carry on doing your research and had patience with you. Did that patience have limits?

I always worked on the basis that I would anticipate questions before they were asked, and therefore I would ask the questions that I thought they would be going to ask in a year or so. So I perhaps was more impatient than they were at the time, but I had little doubt that they would have got impatient. I’ve never had much faith in senior administrators. So I was really anticipating that why should people pay for us to enjoy ourselves like this. It still is a question actually which people ought to ask more often. We can come to that much later on when we get on to philosophy and things. But I was very conscious that we were privileged, we were in a position… we were… well, you probably wouldn’t have had to pay us to do what we were doing once there was the opportunity, that didn’t mean to say that we didn’t count the pennies just as much as anyone else did. But we were enjoying what we were doing, working hard and getting results and competing with the rest of the world, this was important to us, that we should not be second class citizens, that everything we did should be appreciated. And we had extremely good relationships with the Americans. In fact, you could argue that we were on closer terms with many of their laboratories than they were with each other, because they didn’t regard us as direct competitors, they regarded us as scientific competitors, as competitors in what you could achieve, but they would talk much more openly to us than to each other. Interesting, but that was the situation. So we were in quite a privileged position, actually, so we ought to have made progress. If you think about it, if you’re in the centre, so we were talking to all the British companies that we’d placed contracts with, so we had their ideas coming in. We were talking to each of the American laboratories in turn, so we had some insight into how they were thinking, so you could say they were in a way more isolated than we were. They all got together at the Device Research Conference in the middle of the year, and I think I have mentioned this and I will be coming back to that in a minute. But it was a good position to be in.
You’ve talked about the sort of, I guess information flowing to you from American companies, does it go the other way as well?

It has to. They’re not philanthropic, they’re not just going to tell you things unless they think they’re going to get something back, that’s always the case in science that you talk more freely, you talk to the public in one way and you talk to competitors in another way, you talk to collaborators in a totally different way, but they have to justify themselves as collaborators. It has to be a two-way traffic. There’s no point in collaborating with somebody when you’re just feeding them information, unless they’re going to use that information and come back to you. So you choose somebody to collaborate when you can, that has strengths you don’t have, but then you expect to feed on those strengths.

[20:38]
Could you give me an example of maybe information flow the other way, from you walking round all these US labs?

It goes better later on. Well, I can point to one thing. I said there was a problem in making gallium arsenide, in particular in making the crystals. Now, originally progress came from pulling crystals of germanium, and when I say pulling crystals, what you do is you put a seed of germanium into a bath of molten germanium and you pull the seed out slowly so the metal liquid – sorry – the liquid semiconductor then freezes and if you do it right it freezes in the same crystal form as the seed and it is very important in semiconductor devices that you do use a single crystal, because if you use what you might call a bicrystal where there’s a change of crystal form at one plane, one line, then the electrical properties at that line will dominate and you will find that polycrystalline material does not have the same properties as single crystal material because there is a domination. That doesn’t mean to say you can’t use it to some purposes, but it’s by no means ideal. Now, when we came to work on III-V compounds we knew this of course and discovered early on that you could grow crystals of indium antimonide very easily, but that’s because indium and antimony both have low vapour pressures. Once you try and do this with gallium arsenide, which of course we were trying to do, the melting point is high. This was the same problem people had with silicon coming along because the melting point was so high that it was difficult to actually get the molten bath of the silicon in a material that would not contaminate it. With gallium arsenide we had the double problem: not only was there the risk of contamination from the bath because everything was so hot, but also the arsenic has a high
vapour pressure at that temperature, which is 1100 centigrade-odd, that you’re trying to grow the material at. So you have a big problem in trying to keep that high pressure in while you’re growing the material, and there were various ways that came out of doing it. You could try and do it through seals, liquid seals, you could have high pressures outside. We even actually at Malvern – at Baldock – built a crystal grower that would work at the gallium arsenide pressure, but all of the motions going through to try and get the thing pressing were so difficult that you could grow crystals but they weren’t good. At Malvern we had the idea that if you had a liquid on top of the molten material, this was boron oxide, you could pull your crystal through the material, through the liquid, and this was called liquid phase encapsulation. We worked on this, proved it and then we passed it to the others, and that’s the way that is used even now. So yes, there was a two-way traffic. There was also another thing we’ll come to later on with how you do make a pure layer of gallium arsenide, but that comes after I’d moved. [24:50] So let’s still stick to what we were doing here and I will say that some of the things we were doing was of general interest, so we were passing information and it was going both ways. And one of the things we were passing out was our knowledge of physics, and here we come to a development. Remember, although Malvern was the home of radar – it was called the Telecommunications Research Establishment, then it became the Radar Research Establishment – at Baldock we were very interested in radar because we were making the valves for radar sets, the vacuum tubes, magnetrons, klystrons, travelling wave tubes. We were very interested in radar. So in that environment it was natural that we were always thinking of radar sets, how did you make a radar set, a radar system. Now, a semiconductor is quite a complex material inside it that you have energy levels in which the electrons travel. Solids all have these energy levels, but in semiconductors there is a distinctive pattern that you have with a separation between the energies of the electrons that are still attached to the atoms and the energies at which electrons can be free. The way in which this works is that electrons of the highest energy that are still attached to the atoms are not close to them. Because of the general electrical properties of the material, the electrons travel in orbits that are some distance away so you almost can’t be sure which atom is going to be the one from which the electron had originated. So if you can get excess electrons, they will be free to pass through the material, they won’t stay near to that particular atom. But some energy is needed to actually make that electron free and you can think of this as having one energy level where the electrons are tucked into the atoms and another energy level higher up where the electrons can pass through without being attached to any particular electron. And there’s a gap in energy between those two levels that you call the energy gap and I have mentioned before that you can get a photon that excites electrons from being attached to the atom
and that photon has enough energy to actually surmount that energy gap. That energy gap in
gallium arsenide and in silicon is about one volt, a little bit over, and that corresponds to photons
in the near infrared part of the spectrum. In germanium the energy is less, it’s a bit over half,
now three-quarters of a volt, and that means that you can go farther out into the infrared, but it
does mean that if you put energy that is at a smaller energy than that energy gap on the
semiconductor you will not get an electron out. Of course, if you put visible light on, that has a
higher energy so you will get electrons coming, you will get electrons coming from the lower
level to the higher one, but of course you’re wasting energy then, they’ll go higher up. Now, that
is the simple picture. It gets more complicated when you start thinking about the crystal
directions. I said you make a single crystal and if you think about a single crystal, this means that
your atoms are on a three-dimensional pattern and it’s simple to think of this as being a cube that
you’ve got electrons at each of the corners of the cube, and that is a cubic structure. With silicon
and germanium that’s very simple because you’ve got the same atom everywhere. With gallium
arsenide it’s more complicated because you’ve got two atoms to fit in, and of course you hope,
and usually nature helps you, to put them in their right places because you’ve got an equal
number of gallium and arsenic atoms that you have to accommodate. So you can think of this as
a nice inter-penetrating array of gallium and arsenic atoms together and your silicon, and
germanium is a similar pattern but with a clear difference. Now, when you go into the actual
energies that you get from these atoms, you realise that the pattern is more complicated, that in
fact there aren’t just these two levels; the level at the bottom and the level separated by the
forbidden gap, there’s a whole series of levels that are, they may be higher up or they may be
lower down and with gallium arsenide there is a very simple picture, which is that if you plot the
momentum of the electrons as well as their energy, you find that if there is no momentum you
have your lowest energy level. But with silicon and germanium the energy level with zero
momentum is not the lowest one, it’s higher up and to access the lowest energy level in that band
that’s separated you have to apply some momentum to the electrons which effectively is like
giving them some heat. So that means that you cannot get the photon to actually interact with the
electron pattern in silicon and germanium without involving some heat, which is the fundamental
reason why they do not make good LEDs. But then as fortune favours us, in gallium arsenide, for
no reasons that we could have anticipated when we started working on them – and we’ll come to
that in a moment – they automatically lend themselves to this conversion of light into electrons.
So you can think about it, gallium arsenide and indium phosphide – we’ll come to later – there
putting a photon on, you get electrons. Silicon, germanium and even gallium phosphide, which is
a III-V compound, doesn’t work that way. You need photon plus energy before you can get it,
and that is an inefficient process. There are things you can do to help it by adding impurities and by straining the crystal, but automatically it doesn’t happen and that’s how we were able to make these infrared LEDs. [33:25] Now that’s when it becomes really interesting because we started looking at transitions between these levels. It so happens that electrons will move through a lattice, a crystal lattice that is at zero temperature, very freely, unless you have impurities and grain boundaries and things. But you can’t avoid some collisions, as the electrons move through, with those atoms in the crystal and those collisions will become more serious as the vibrations in the crystal, because of the temperature change, become more violent. So you expect that your electrons will travel more easily through a crystal when it is cold than when it is warm, and you’re well aware of that. And you have what we call scattering processes, processes that go on in the crystal because the electrons are not travelling in free space. And with silicon and germanium you will know that those atoms all have a charge on them, that when the electrons are free, so you get some effects. When you have impurities in, you get much more serious effects because the impurities are charged and of course electrons are charged. So if you put impurities in, you expect the freedom with which electrons can move through that crystal lattice will be restricted, so you will have what is called impurity scattering. When you have the III-V compounds it’s actually worse, because the atoms themselves have different charges, so you can say you have a dipole there, a plus and a minus, and that’s going to affect the electrons considerably. So you might imagine that in the III-V compounds the electrons travelled more slowly than they do in silicon and germanium, because you have all the effects that you might expect from silicon and germanium, plus this charge separation that you’ve got on your two atoms. And yet, we find that in gallium arsenide the speed with which the electrons can move is ten times greater than it is in silicon. How can that be if we’ve got this extra charge giving us more scattering? The answer is, we’re not comparing like with like. The energy level in which the electrons travel, that lowest energy in gallium arsenide, being at the zero of momentum means that the electron is much more able to travel than it is in the other levels that were present as the lowest level in germanium and silicon and gallium phosphide. So we are getting a bonus, we’re both getting the properties of getting light out, at the same time we’ve got a very fast level. I can probably best explain that by saying we have a concept in semiconductors. Associated with each energy level we have an effective mass of the electron and it’s fairly obvious that if you have a light electron it will travel faster than if you have a heavy electron. So what I am saying is that in gallium arsenide, normally at low electric fields the current is being carried by light electrons, whereas in silicon and germanium it’s carried by heavy electrons. So in spite of the fact that you’ve got this extra charge on the atoms, that doesn’t compensate. Indeed, you can say that if
you didn’t have the charge but you had this light mass, the electrons in gallium arsenide would probably go a hundred times faster than silicon and germanium. But the fact is, you’re not comparing like with like, that you have, you certainly have these levels present in both, in all of silicon, germanium, gallium phosphide, gallium arsenide, indium phosphide, they’re all there, but the pattern is different. The pattern in gallium arsenide and indium phosphide is that your low mass levels are the ones that are normally used, they’re the lowest in energy. They’re the ones that the electrons get to once you excite them from the lowest band above the forbidden gap, they will be in the light mass levels. In silicon and germanium and gallium phosphide they’re not, they go up to a heavy mass level, which is interesting because you wonder, can I move electrons from one level to another. Up there, can I get them moving from a heavy level to a light level or a light level to a heavy level? Well, the answer is well, yes if you know what you’re doing, and what is more, you know that you can play around with these levels, you can move them up and down relative to each other by actually applying a strain or a pressure on the semiconductor and at this stage in the search for knowledge of the semiconductors, people would apply high pressure experiments. And indeed, we actually had a group at Harlow, which I’ve mentioned earlier, became very prominent in this, in designing high pressure equipment so that you could put either complete universal, homogeneous strain on the crystal, or you could put the strain in one particular direction and you could move these levels relative to each other, and we knew how they moved, how they moved with pressure. [40:29] And, now, I had mentioned earlier that I had written with Christopher Rose-Innes this book on semiconductors, III-V compounds, and we dealt pretty thoroughly – well you have to in a book, obviously – with the general physics of the materials, then we dealt with a material called gallium antimonide, which was interesting to us because you never seemed able to do with it what you thought you could. If you actually grew relatively pure indium phosphide or gallium arsenide or indium antimonide, they would come out n-type, which meant that normally you’d get electrons travelling rather than holes and you could dope it so that you got the holes travelling, but normally as you made it, it would be n-type. We later learned this was almost certainly due to silicon doping from the boats in which we made the material, and silicon acts in a strange way, as you can imagine, because it’s neither a second group or a sixth group, it’s in the middle. But it does act n-type in a rather complicated fashion and that was giving us our residual impurity concentration. But now we were dealing with a material called gallium antimonide that was normally coming out p-type and you could dope it n-type but this wasn’t what you normally thought of doing, but you could do it and there were some groups in the States which were working on it. We didn’t have much work going on in the UK, but naturally in the book we had to describe some things that were going on in gallium
antimonide. Now, when you’re working on a semiconductor, you naturally want to find out what the basic parameters are, and the two essential things that you want to know about the electrons is how many are there, and I’ve mentioned numbers like $10^{17}$ and I wished to get them down to $10^{15}$, and the speed with which they travelled, the mobility. And you get at these things by doing some pretty basic experiments. You get, when you measure the resistance of the material, which is pretty fundamental, and you deduce the resistivity or the conductivity, you get a number out. Unfortunately, that number depends on both of these properties. The number of electrons that are travelling and the speed with which they travel, and you can call this the mobility of the electrons or holes. And the mobility is in units, it’s centimetres per second for an electric field of so many volts per centimetre. I think it is obvious that the higher the field that you apply to the material the faster the electrons will go. This doesn’t apply at the highest fields, but at the fields which you would be going. So you get a number out which will be a few hundred or a few thousand or a few tens of thousands of centimetres per second per volt per centimetre. So, we’ve got those two numbers that come in and you want to separate them, because you want to know what the ‘$n$’ is and you want to know what the mobility is. You do another experiment, which was designed by a gentleman called Hall in the 1800s, who showed that if you apply a magnetic field to a material, the electrons, as was shown in the electric motor and various other things, will not travel in a straight line, they travel in a curve and because they travel in a curve you can get them to charge up various surfaces and if you take a square of a material and you put electrodes on the four sides, if you apply a voltage across a pair, you will not normally get a voltage across the other side because the electrons will be travelling at straight lines from your negative electrode to the positive electrode, from the cathode to the anode. If you apply a magnetic field though, you will now get a charge developed across those two, across the other two electrodes, those at the side, because the carriers are no longer travelling in a straight line from cathode to anode, they’re deviating and the holes will go in the opposite direction to the electrons. So, first of all you can tell whether you’ve got an ‘$n$’, a negative type material in which the carriers are electrons, or a p-type material because they’re holes. Moreover, you actually, by the arithmetic you can do on this, can immediately determine what the number of carriers is, independent of the mobility. So now you have your, since you’ve got your one number, your ‘$n$’, you can deduce what the $\mu$ is. So that’s what you do. Now, the interesting thing about gallium antimonide – I keep using the word interesting, because it is interesting, fascinating would be another word. You will appreciate that as you increase the temperature in a material, you will get more electrons excited from that band at the bottom where they’re attached to the atoms – we call that the valence band
where they’re attached, but you’re applying more energy to the atom and that goes to the electrons, so some of them will go up to, through the forbidden gap, to the conduction band where they’re free to conduct. And you know this because it clearly comes out from your measurement of resistance and the Hall effect, and this obeys quite straightforward rules and you know the pattern that you would normally get. In gallium antimonide you don’t get that pattern and that was very curious as to why you didn’t. And the reason was that those sets of energy levels that I’ve mentioned before, the silicon-like levels, and the gallium arsenide-like levels are very near each other. It is true that the bottom level is still the gallium arsenide type level, the light mass level, the fast electron level, but the other level, the heavy mass level, the silicon-like level, the slow level, is very near it in energy, as a result of which, as you increase the temperature you actually can move electrons from the fast mass, the high mass, the high speed level, to the low speed level and the sums are different because you’re now no longer dealing with one type of electron. And you learn how to cope with that. The thought that set off in my mind was, can I do this electrically. I know that if I apply an electric field to a material, one effect is that the electrons will move through the material from cathode to anode, but what does that mean? What it means is, you’re actually applying energy to those electrons. Now you have to have in your mind this pattern of energy levels, you have the valence band, which is the lowest energy we’re concerned with. You’ve got the forbidden gap, which is one electron volt higher, shall we say in gallium arsenide – it’s a bit less than in gallium antimonide, that doesn’t matter. And then you’ve got a few more tenths of an electron volt higher up, the slow levels, the higher resistance, the higher mass levels. But on this pattern as I apply energy to those electrons by increasing the electric field, I have to represent that on the diagram by the electrons climbing up in energy. We have a diagram that shows it, that more or less represents the electrons in that level as in a cup, rather than in an extended level in one direction, it isn’t quite like that. It is a cup and we’re normally working with the electrons at the bottom of the cup. As we apply an electric field they begin to creep up the side and the thought occurred to me was, can I actually get them to creep up the sides of that cup far enough so they will jump across into the heavy levels. Now why should anyone in their right mind want to move electrons from moving rapidly through the material to a level where they’re going to languish and move slowly. That involves you in some more detailed thought about what happens in these materials. [51:35] Now one of the things people had become interested in was negative resistance. Negative resistance is a concept which has to be explained quite carefully, because you’re not talking about the electrons moving towards a negative electrode, the electrons will normally move from the negative electrode, the cathode, to the positive electrode, the anode, and we are going to keep them doing that. What we
mean by a negative resistance is a negative differential resistance, though in our jargon we often
don’t bring in the word differential, we talk about a zero resistance, it’s really a negative
differential resistance. Normally carriers in conductors obey Ohms law. That was discovered,
again in the 1800s, by a man called Ohm who said that the current that you get is proportional to
the voltage that you apply and the constant of proportionality is called the resistance and we have
an equation, $v$ voltage equals $i$ current, times $r$ resistance. And that’s how we define resistance.
We know that that is not always true because as you apply higher fields you can get
complications coming in. The first complication is that the material heats up as you apply a
higher field and then the electrons will be scattered more by the electrons, so the resistance will
be changing, so you can get the curve flattening off instead of it actually going up, as you might
say, by a hill of finite slope and fixed slope, it will begin to curve over until it saturates. But what
happens if you do something to the material so it doesn’t just saturate but starts going downwards
so that as the field increases the current drops. That’s nonsense, I mean that throws everything
into kilter, into, I mean you don’t understand what’s happening now. I mean the pattern of
equilibrium has been interfered with fundamentally. If you now think about clouds of electrons
moving through the material, what happens when Ohms law is being applied? Well, we know
that when you get clouds of material you get charges developed, fields being developed in it and
we have calculations which show what happens to that pattern and it so happens that when you
do those calculations you can show that if a few bold electrons decide to go faster than their
neighbours because they want to get to the anode quicker, then they automatically create a
decrease in the local electric field so they will then go slower. In the same way, if there are some
recalcitrant electrons that want to hang around and not get to the anode with their friends and
neighbours, automatically the field locally will increase so they are forced to go faster, so the
statistics of the electron motion means that Ohms Law is obeyed. In other words Ohms Law isn’t
an accident, it’s actually a fundamental property of the material and the details of the charges that
develop within the material that give you Ohms Law. It then follows that if you are getting a
fundamental departure from Ohms Law, not a saturation, but a negative differential resistance,
you can say all hell gets let loose inside the material, because any electron that wants to go faster
will be in a higher field so it will go faster and faster and faster and run away. And similarly, if an
electron decides he wants to go slower the field around it will get less, so it’ll go even slower. So
the whole equilibrium pattern of the material is broken up and this was analysed very early on by
Shockley. Shockley, remember, was one of the inventors of the transistor, he was a very clever
theoretical physicist. I’m not saying anything about his character here, which was criticised quite
heavily later on in life, but he was a very good physicist, and he analysed this situation of a
negative differential resistance and showed that if you had a negative differential resistance in a material, that you could get the whole material behaving unstably and as a result generating microwave radiation. Now this was of course an interesting topic to people, but it was no more than an interesting topic, people were willing to look at it. \[58:05\] And they tried to look at it first of all by saying that you could show theoretically that if you applied electric fields in particular crystal directions in germanium, because of the complex nature of the energy levels you could get actually electrons going into a region where they behaved as though their mass was negative, and people were working on that to see if they could get that to happen. Now in fact that's really like thinking about that cup I told you about where you can talk about the actual electrons being in a cup, and in fact the mass can be described as that diameter across the cup. In other words if you have a very narrow cup then that's a low mass. If you have a wide cup that's almost getting flat, that's a very heavy mass. But now think of the top of the cup when it turns over to go from one cup to the next cup, that mass is negative and can you get your electrons poised actually at that place where the mass is negative. And people worked for some years on trying to do that. In our laboratory we had a very good physicist called Emlyn Rhoderick and he showed just about this time, 1961, that this was impossible, it couldn't happen, you could not get it. He went through the whole physics of it and said people are more or less wasting their time because this is only a concept and you cannot get it to happen, there are other things that will come in that stop it happening. Good, fascinating physics. As far as we were concerned it was a topic of conversation in the laboratory, that could you get a negative mass, and he'd shown you couldn't. But of course it meant that we still had at the back of our minds this idea that if you could somehow get the material to show a negative differential resistance you would get interesting things happening and you might get the whole material being unstable and giving you a possible microwave source, which would have been really intriguing for us as a radar place. But how do you do it. And then my thoughts had been going on the gallium antimonide and I thought well, think about gallium antimonide and let's make it pure and apply an electric field to it, can we calculate what's going to happen. Now you can see that in fact you can represent your semiconductor by two lines on a graph of current against voltage. If I am thinking about gallium arsenide I know that if I apply a voltage I get a high current because I'm dealing with light mass materials, fast electrons. So I've got a steep line. Think of that on this plot. You've got your $x$ axis, which is your voltage, going horizontally. You've got your $y$ axis, which is your current, going vertically. And I draw a straight line that's steep on that. Now think about silicon with this slow electron, high mass, low conductivity, high resistance on that diagram, I get a line of shallow slope going out. Now, take your pen and move it along the fast line and then I want you
to drop it suddenly to the slow line. And what have you drawn? You’ve drawn a line of negative
differential resistance. So, what I’m saying is, if I can get my electrons to move from this fast
conductivity, this high conductivity line to the slow conductivity line, I’ve got a negative
differential resistance, not necessarily, because I’ve got to do that over a small change in voltage.
I can also go from one line to the other gradually. If I draw a line that’s more or less saturating
between the two I could progress from the high conductivity line to the low conductivity line over
a long change in voltage and I wouldn’t get a negative differential resistance. So how do I now
show that it’s going to happen, because I’ve got to believe it’s going to happen, I’ve got to show
that that change will happen over a short change in voltage. Okay, let’s do some calculations.
And if you do those calculations you realise that in these materials like gallium arsenide and
indium phosphide and indium antimonide, as I mentioned the thing that was limiting the
movement of the electrons was this charge difference between the two atoms. But you can show
that that effect suddenly gives up at a certain electric field the carriers are no longer restrained by
that charge and they rush away, and indeed, the material then wants to break down, it actually
wants no longer to restrain the electrons at all and you would get an enormous increase in your
current at that electric field. But that doesn’t happen because there are other energy levels. That
light level is only having a temporary effect now on the low electric field electrons. If I apply a
high electric field, automatically the material gives up in its attempt to control the electrons by
that charge separation, but now the other mechanism comes in, the mechanism that was
restricting the carriers in silicon and germanium-like materials which of course are the upper
levels. So what the material is telling me is that automatically at a field it will do that first
transition line that you drew, in other words, the negative differential line. And I could work out
what field it will happen at. It will happen at a field of 3,100 volts per centimetre in gallium
arsenide. Now, 3,100 volts per centimetre is quite a high number, but you think about it, it means
that if I have a piece of material that is ten micrometres thick and I apply a voltage of 3.1 volts
across it, the material will become unstable. Sounds nonsense doesn’t it? Take a piece of
material and you put three volts across it and it sort of goes haywire, it no longer obeys Ohms
law. Hm, very strange. Must be something wrong, better go checking your arithmetic. [1:06:50]
So, I did the calculation, I checked my arithmetic, I showed that it actually would work in gallium
antimonide, but not very well, because in gallium antimonide you automatically got carriers
transferred by temperature from one level to another, so the whole effect would be blurred, you’d
have to cool it to 77°C to see it, and that’s what I did in my first calculations in 1961 and showed
the gallium antimonide would not work. So then I decided to try it on gallium arsenide, and to
my surprise I actually predicted that curve that you drew, going up first of all with Ohms law and
pretty well obeying Ohms law until about 2,900 volts per centimetre, then coming over and coming down pretty rapidly, very difficult to actually predict the line there as to what the slope would be, but you could see it would come down very rapidly, and the reason why you couldn’t predict it is the voltage across the material no longer made any sense because it wouldn’t be behaving as a uniform material. Right, so well, got Emlyn to check what I was doing, Emlyn Rhoderick. He said it looks right, don’t understand it. So I published it. I got some complaints from the referee which was, held it up and things, and then I discovered quite out of the blue that the group at Salfords, near Redhill, the Philips laboratory, though then I think it was still called the Mullard laboratory, had done the same calculation, and they’d done it a little bit before me, but they hadn’t done it for gallium arsenide. They’d done it for germanium. Now it wouldn’t work for germanium would it, from all I have explained to you, but what they had said was, if you strain germanium you can actually move those energy levels in the material so that the fast level is actually below the slow level and then of course it begins to look like gallium arsenide. And they’d done the calculation, said you get a negative resistance in germanium. They then added at the end, you might get the same thing happening in gallium arsenide, but they didn’t actually do the calculation. I had done the calculation more or less at the same time, a little bit after them. They published and in fact they published between [1:09:45] the time at which I’d submitted my paper and the time my paper was published, because there was a delay because of the refereeing. So when it came to the 1962 Device Research Conference – remember, I’ve mentioned those earlier – this was to be in Stanford. I went, I had submitted my paper and I could submit it to them before it was published, so it appeared as an abstract and they wanted me to present it, so I presented it there and people were interested, I’m not sure anyone believed in it, seemed ridiculous that you could actually get the material breaking up like this. And they asked me a question about this and I said, well, in fact the best person to answer that is not me, but Brian Ridley who is in the audience. Now, the story gets rather detailed here in that the authors of the paper from Mullards were people called Brian Ridley and Tom Watkins. The laboratory was not interested in gallium arsenide, they were interested in silicon. This is, Brian was a theoretical physicist, a very good theoretical physicist, and Tom Watkins was mainly the experimentalist. Tom had visited the States later. He visited the States and went around and in fact he carried on too long visiting the States even though he was ill and he came back, this was two or three, two years later I think, he came back to the UK but the problem he had had got too serious and he actually died quite young, which was pretty awful. I’m telling you this because we’re going into the history of people. Brian left Mullards, he was a serious… he went to the University of Essex and became a very prominent figure in semiconductor physics and I know
him very well and he’s a Fellow of the Royal Society, has done very well. But it meant that Mullards did not do any more work on it, nor has anyone else, so it’s never been shown to happen. But anyway, I said Brian’s in the audience and he should get up on the stage. He came up on the… and he said, yeah, sure. And he jumped up on the stage, stood by me and there came a gasp from the audience. And I looked at him and he looked at me, we shrugged our shoulders, carried on, and he answered, I answered questions, everyone was happy. But afterwards I said to somebody, ‘What was this gasp?’ And he said, ‘You don’t know?’ I said, ‘No, I don’t know, what was the gasp?’ He said, ‘You’re twins. You just look, it looked as though you were standing by your side’. And I thought, really? I mean… and he didn’t know this, but apparently at that stage we looked very similar – I’ll tell you a story later on, but not for this, about that – which was interesting and as the years have gone by we make jokes about this, about our similarity. He, actually I think, he’s probably ten years younger than me, but I don’t think he looks it now. He’s had a harder life than me at the University of Essex, I’ve not been in the stresses of academic life so I haven’t aged as fast. But anyway, we both knew, he agreed with what I’d calculated, he was a bit irritated that I had done the calculation for him, I was a bit irritated that they sort of published before me, but good friends and it was fine. And then he went back and I think it was while he was in Essex, the next year that he actually analysed what would happen in a way that Shockley had not done. Now, I had touched on the fact that what happens with these recalcitrant electrons that go slower and the ones that go faster as to what happens and in Ohms law how that gets smoothed out. Brian did a complicated analysis of what happens and showed that in fact the material breaks up into domains, that what you get is regions in the material where – let’s put it this way – that you can show on that diagram you drew, there are three field regions. At low fields there is a region where Ohms law is obeyed. At high fields there is a region where Ohms law is obeyed and it’s in between that you get the negative differential resistance. And nature hates that, so what it does is it makes the material break up into regions where there is a high field and regions where there is a low field. Because there is a high field, that means it sucks up voltage, so it’s got to be narrow. So you get narrow regions where there is a high field, broader regions where there is a low field, and of course this whole structure moves through the material because the electrons have to go from cathode to anode, so you get high field domains. So you can think about this and you can just draw a pattern where you’ve got some high field domains, say three or four high field domains, moving through the material all in synchronism. In fact, if you analyse it properly you find that what you get is one high field domain that takes up this excess field and because it’s in a high field it actually can move at the same speed as the low field domains that are going through. So the whole thing
moves together and you get a high field domain created at the cathode, it moves through and collapses at the anode. And of course it moves pretty fast. [1:16:40] Well, of course we thought this was pretty good and immediately tried to see if we could do it, can we actually do it. Now, we couldn’t purify gallium arsenide and the only way we could really show this was working was to get extremely fast pulses on the material so it didn’t get a chance to heat up, but we weren’t clever enough to do that. We tried, but even though we worked with sub-microsecond pulses all we did is blow up the pieces of gallium arsenide we were using. We couldn’t do it. We tried cooling it and various things. And then we thought we had discovered a way of doing this and this involves another peculiarity of gallium arsenide, fascinating material. We found that when we made gallium arsenide, if we took these pieces out from the wreckage, which I did mention, when the material blew up, some of these samples were insulators in fact. I mean when you have a lot of impurities in a semiconductor you expect that it’s going to have a very high conductivity. You’ve got lots of electrons moving through. But some of the pieces we had were effectively insulators. They weren’t insulators like glass, they had an extremely high resistivity that could easily be a million Ohm centimetres, as opposed to the one Ohm centimetre that you would like to think of for your silicon and germanium and less than that with our normal doping that we had automatically. And here were these pieces that were high resistance. The only way we could picture them, and we did a lot of picturing them and writing papers on this material, which we called semi-insulating gallium arsenide, that we said in some way the impurities are giving traps and levels in that gap which is supposed to be forbidden to them between the valence band and the conduction band we’re getting some trapping levels which we had known existed from earlier semiconductor work, which is trapping all of the electrons that are available and given this. And we did a lot of work on trying to analyse. But here we thought, well, we’ll try a high electric field, which we hadn’t tried before on the material. Take our pieces, I mean it’s not that difficult an experiment. Let’s say you take a sample that’s a millimetre separation between anode and cathode and then all you have to do is to apply three or four volts to it. No, thirty… sorry, 300 or so volts to it, which you ought to be able to do with reasonable pulse, that’s not difficult. And then we realised if we took a really thin layer we could apply a sample, but before we could get up and when we started turning the voltage generator up and it was a very simple circuit, you just had a DC supply that you could obviously buy and you turned this as voltage up and you had your sample of semi-insulating gallium arsenide and you had a meter which measured the current. And you turned it up and suddenly you noticed that the needle on this meter was going up and down and up and down. I mean you watched this and thought, what’s going on here. And it just would oscillate at one per second, one every two seconds, one every three seconds, and you
called in your friends to come and look at this, look. And they’d say, ‘What have you got here, where’s your circuit?’ And you’d say, ‘Well, I’ve got a source of voltage here that might be ten volts’ – and you could do it with a battery as well, I mean ten, twenty, thirty volts, ‘and there’s a piece of gallium arsenide and there’s a meter’. They’d say, ‘Give it to me, let me have a look’. Yes. Well, we did some research and we in the end decided that what we were getting was domains going through the sample and this was actually known on materials like cadmium sulphide that people had done, a man called De Boer – D-E-B-O-E-R, might be an ‘s’ on the end – had shown years before and we were getting this but it was most mysterious and much more developed than he had seen. [1:22:15] In fact, we were beginning to collaborate with some people in France on this and a man called André Barraud had been working on gallium arsenide and he came over to work with us and the first day we took him into the lab and we said, ‘What are you, I mean what are you working on?’ He said, ‘Oh we’re working on semi-insulating gallium arsenide’. We said, ‘Semi-insulating?’ He said, ‘Yes, we’re trying high fields in semi-insulating gallium arsenide’. And we looked at each other and said, ‘Well, come into the lab’. And we came into the lab and we turned this on and showed him this, he said, ‘Ah’ he said, ‘You see it too!’ And clearly he was most relieved because they’d thought they were going mad. ‘Ah, you see it too!’ And yes, we were seeing it too and it was a damn nuisance, I can tell you, because it meant we couldn’t do our experiment that we wanted to do to show high field effects and negative differential resistance.

*Because the French had done it first?*

No, we did it at the same… we did it first, we didn’t publish it then, we thought people would think we were crazy. I mean, you take a piece of material, you put a battery on it, you have a meter and the meter goes, *rurrhh, nnyah, nnyah, nnyah, nnyah, nnyah*. You have to have an explanation. We didn’t have the explanation then, we didn’t want to tell people that our needles oscillated. Nor did he. Nor did… But in the end we did publish it as low frequency oscillations. But it was, the main point was it stopped us from getting any further with our experiments because we didn’t have the fast pulses to actually get it happening in ordinary doped gallium arsenide, nor did we have the ability to do it DC on semi-insulating material. So we were stuck, not quite knowing how we were going to really do the experiments that we wanted to do. And this was 1962 and that – your arithmetic is good enough to work out that is fifty years ago. And just at that time the semiconductor laser came along. The injection laser was actually invented in September, 1962.
I think before…

And its fiftieth anniversary is being celebrated in Warwick this year.

[1:25:00]

Before we go further on to the semiconductor laser there are a few questions I want to ask you about what we’ve just discussed. And in particular I guess we’ve had a very sort of physical explanation of how this all works. I’m just sort of trying to root that in sort of day-to-day activities a little bit as well. One of the things that occurred to me was, I’m sort of sat here drawing little diagrams of electrons moving between crystals and that sort of thing, how do you actually visualise it when you’re working on it in the lab? At that time?

Well you could visualise it as these cups that I have mentioned, that you can… You actually cannot do semiconductor physics without knowing some quantum theory. You can do some semiconductor work without doing it, but you see here is the pattern that I can show you of the different materials, and that is the band structure but you see there’s another axis here, which is crystal momentum. I’ve had to show you the energy level. If you think of energy levels you normally think of them as going as flat lines across a diagram and it just is showing you energy and the horizontal axis doesn’t mean anything, it’s just because you can’t do a diagram with just points, so you do it as a flat line. If you bring in the actual quantum theory, the way in which a semiconductor actually works, then you bring in crystal momentum and all kinds of complications to do it and you get this pattern. Now, somebody who works on semiconductor physics will sort of have this as their bread and butter and will know the difference. I mean I’ve drawn on here – I haven’t even bothered to show you silicon and germanium, but you will see that in gallium phosphide the actual level at the centre of the momentum diagram is in fact higher than the level in another crystal direction. And what you were doing when you applied pressure to something like this is you’re tilting this diagram up so that it tilts from here so that this level now comes higher than that one. But that’s how you picture it, you do picture it as a cup, as I’ve drawn it here. And there is quite a lot of physics in that cup because in its simplest form it’s a parabola. The energy that you give to the electrons moves them up and you can think of them going up at the sides of the parabola and it’s not quite a parabola, it varies slightly and there’s quite a lot of physics in those variations. But people weren’t that interested until we started exploiting the band structure and in fact as we’ll get later on, I brought in a term here - it’s quite a
bit later on, 1971 – called band structure engineering where you play around with those energy levels by the way in which you make the material, that you can make materials and play around with those energy levels, you can actually engineer them. And that is now done.

[1:28:50]
I think one of the other things that occurred to me here was obviously we’ve sort of talked about how sort of one problem, question led to another experiment on something else and I was wondering are you actually aiming at anything here or are you just finding out what’s…

No. Well, no and yes. We weren’t clear in our minds what would happen, but there are various topics that come up and people talk about them as bandwagons. They’re not quite bandwagons because a bandwagon indicates that something is successful, but indeed there are certain things that become popular as topics. One of them for instance was electron-hole drops where people became very interested over a period of years in what happens if you get agglomerations of electrons and holes and a number of people would be working on it. I mention that because we never did. But there were groups working on it and if you look at the proceedings of the Semiconductor Conference, which we will get to, you can see topics coming and going or coming and coming, and what you want to do is to work in the topic that’s going to keep coming, but you don’t know that it’s going to keep coming right at the beginning. And although people had been interested in high field effects in semiconductors, from the point of view that you could get plasmas in solids and you’d get interesting effects from the plasmas and solids, it was in fact the negative differential resistance that really set off the high field effects and that has never stopped. A lot of the interest in semiconductors is what happens when you apply high electric fields to them and do move the electrons among these different energy levels and there are lots of things that you can do with that.

[1:31:00]
I guess one of the other things that interested me as well is the scale on which this is actually happening, because again, you know, we were talking about graphs, I’m doing my diagrams, but we are actually talking about electrons, little tiny things. I’m just wondering how the sort of balance here between the sort of experimental work and the theoretical work I’m not quite clear on either. Can you give me some idea of how much of this process you’ve discussed is actually you sitting down with some results?
Well, you get, first of all you have to get, you get three kinds of physicist. You get the theoretical physicist who sits at his desk and thinks about semiconductors or superconductors and he uses a pen and paper and a computer and probably never leaves the room. You get the experimentalist who’s interested in materials, I mean he might be interested in making a material, material scientist, he wants to know how to make gallium arsenide. I can think of crystal growers, really quite gifted people like Brian Mullin, Don Hurle, who probably wouldn’t know what the band structure, well they might not know as a primary interest what the band structure of gallium arsenide was. They’re interested in making it, making perfect crystals without defects, understanding those defects, understanding how you make good crystals, the process that you use, inventing ways of doing that, worrying about impurities, how do I get rid of impurities, but never give a thought to what’s going to happen to the material after and how you turn it into device. Interested in the process and some of those will be people who veer into actual experiments doing it. And then you get the people, probably like me, who are interested in the whole gamut of the thing, but particularly interested in how does this device work. They want to know about the manufacture because they want to be sure that they know what is happening. But they’re also willing to sit down and put electrodes on and actually apply electric fields, observe what is happening and work out how does it happen, why does it happen and how can I make it a better effect and how can I use it. And they’re that kind of people. The kind of person you don’t want in this is the kind of person who says I’ve discovered an effect, somebody ought to find an application for this, and that’s anathema. Yeah, because it shouldn’t be somebody else who does it, it should be you, because you should know more about it than anyone else and you should be interested in maximising it, or thinking about it and thinking there isn’t a use for it. So I’ll publish it and there might be somebody, but you shouldn’t really take yourself and say I have taken this to this stage, I have found an effect, there ought to be somebody somewhere who can find a use for it, and it will astonish you how many people are like that. I certainly used to come across it and I wasn’t short in taking them to task over it and saying you’re the person who understands this effect, you’re the person who should be maximising and finding a use for it, if you think it’s got a use. I don’t mind effects that don’t have a use, that’s fine, but to actually think it’s got a use but somebody else ought to be finding a use for it, and I mean I would have thought there are ten or a hundred times as many effects that have no use as those that do have a use.
Situating yourself on that scale then as being somewhere in the middle between experimentations and—sorry, experimentalists and theoreticians, [1:35:10] are there literally experimentalists and theoreticians around you in the laboratory?

There are, yes. Yes, I would say that—well, I can think of two people in our lab who were theoreticians. There was Bob Barrie who went to Vancouver and ran a group of theoretical physicists there, and there was Gerald Rickayzen who went to University of Kent at Canterbury, then he spent some time I think in Illinois before he came back. Actually he lives in Pinner now. And he, they’re both complete theorists, they’re theoretical physicists and indeed, the difference between the way of working that came to me a year or two later was of immense difference, was in fact at Malvern there was a very powerful group of theoretical physicists, some of whom did do experiment, but there were others, Paul Butcher and Bill Fawcett, who never did an experiment. They were professional theoretical physicists and there was a group there of professional theoretical physicists and they were a key feature in what we were doing in the later half of the 1960s, being with a group like that.

To get back to the gallium arsenide as well, who were the experimentalists on the other side of this graph?

There was me, I certainly would get my hands dirty and do things and be a nuisance. We had three young recruits: Brian Holeman, Ken Hambleton, Colin Gooch. I had already mentioned Arthur Cunnell and Jimmy Edmond who were still around but not in the later part. Better think harder, I don’t want to leave anyone out. Oh… no I don’t… my list of publications doesn’t actually… Well, that shows the cups.

More like cups than…

[pause] I think they were the main ones at Baldock. There were others who came in and there was Walter of course, my faithful Walter Harding, who did a lot of the preparation of the samples and also some of the experiments, but I’ve mentioned Walter at length earlier. So yeah, there were… Oh, Mike Coupland, who later went to STC. Derek Oliver who was a definite experimentalist. Mike is dead now. Derek is still around.
Can you give me an idea of... So you've situated yourself on this scale; theoreticians on one side, experimentalists on the other, over the sort of work we've discussed on gallium arsenide, what's your sort of daily interaction like with both those groups?

Well, my interaction would be mainly with the experimentalists because now we're talking about me being a group leader and being sort of personally responsible for the programme and the group and the group was probably about ten people now. And Ian Ross had come and we were split up into three groups, essentially. There was my group which essentially was now doing gallium arsenide, there was Oliver Simpson’s group which was one of the first groups to start working on organic materials and – organic materials – organic semiconductors, but then they were things like anthracene which he was working on with people like David Northrop. And there was a third group doing materials which was under Phil Gurnell, who was a chemist. I interacted with, quite closely with some of the people in Oliver’s group. I’ve mentioned Emlyn Rhoderick, what I haven’t said is Emlyn and Christopher Rose-Innes had moved away from semiconductors and were beginning to get into superconductors. Oliver’s group, Oliver was a kind of deputy to Ian Ross and he certainly wasn’t working on these things. He was quite powerful in theoretical physics, but in his group were the two theoretical physicists: Bob Barrie and Gerald Rickayzen. So I would consult with them occasionally, but Emlyn was no slouch in theoretical physics and you could talk with him. Nor was Christopher of course. If you look at the book on semiconductor compounds, Christopher was responsible for the more fundamental part of it. I was more responsible for the devices and the actual phenomenological part of it. So they were there for you to talk to. In fact geographically, it’s interesting because my area was sort of split between two parts. I was partly in the building outside, but also in the main shed. I had a laboratory there which really had been inherited from the infrared group which had disappeared by now of course. You interacted with them when you wanted to talk about some subject and you’d have coffee with them. There was no hierarchical separation.

One of the other things that’s occurred to me as well is you’ve sort of mentioned doing experiments along the way, but I’m just wondering if we could maybe sort of do a sort of visualisation of some of these and you mentioned, for instance, the difficulties making indium antimonide. I was just wondering, how do you actually make that in the first place?
Well actually, indium antimonide, I wouldn’t say that was difficult, it’s because it’s easy. I mean everything melts at low temperature, you just put the two together and you just put them in a pot and heat them up, essentially, and you have to make sure that nothing else gets in when you’ve heated it up. So you have a crystal grower that you can evacuate or put at a fixed pressure and you try and ensure there’s nothing other than indium or antimony in it and indeed, it’s relatively easy to get it down to the $10^{15}$ level. Now, what I haven’t said is what you do in the background to get pure indium and pure antimony and I had to have contracts with people. Yeah, I suppose it is necessary. Yeah, you have to organise yourself through CVD to have contracts with people who were prepared to purify the materials. And I had contracts with… I know the people were down at Windlesham in Surrey or something. Remember, we had different contracts with people on materials like indium, gallium, antimony, arsenic, phosphorus. One of the companies that we got involved with said they didn’t want to get paid to actually purify the material, what they wanted is a guarantee we’d buy the material from them when they did it. They would obviously please the present Conservative government. I will say that was a little unusual. Most of the people wanted to be paid to actually do the purification and when they did it we would buy the stuff from them because we wanted it, they could do it. And of course Malvern was also interested in indium antimonide because they wanted that. So it was quite organised. Also what was organised were the ways of purifying, of testing it. This was interesting, if you had a contract with a company that said you will make us indium that is pure to one part in a million, okay, so that’s a contract, but you have to write into the contract how do I judge that you’ve done this. And they wouldn’t be happy if we were doing the judging, so we had to involve people who could do that. Well that involved mass spectroscopy and at that stage people did have pretty sophisticated mass spectrometers that had a large magnet and the stuff did whirl around in circles and different atoms of different weights finished up in different parts of the equipment, you could measure them and you thought you could get to one part in the $10^{16}$, so they would measure the sample. I can remember them objecting violently to a measurement we had done on indium and the people, I think it was Metro Vicks in Manchester – it could have been AEI in Rugby were also doing it - reported back that this material had 1% of silicon in it and the people objected violently to this thing until I pointed out there actually were bits of glass in it, that in some way they had got glass in their sample and they were really upset about that. I mean they didn’t know, I mean it could happen to anybody, but it happened to them. Metals Research I think was one of the companies. [1:47:25] Then of course, you also were interested in the actual materials in which you were making the thing. We mostly were making them in quartz, which is a very pure form of glass. You couldn’t make them in normal glass, glass is full of all kinds of things, a glass form, to
make a glass form in. So we had pure quartz and then we decided what we needed to use was synthetic quartz which was called Spectrosil, which was made by a company in the north of England and they said they would make us a special form of Spectrosil that they guaranteed would be pure. Well then of course we could get the Spectrosil checked as to how pure that was and when the results came through, the company which I think was called Thermal Syndicate, was not amused because they said that this special form of Spectrosil is no purer than the normal form of Spectrosil that you used. And when I reported back to the company they were quite abusive and said that can’t be, I mean it goes through a different thing, and when I asked to look at what they were doing I pointed out that at the end when they were forming the actual samples that they were sending us - tubes and boats in which we melted the thing - they were using the same tools that they were using for the standard form of Spectrosil. And I said, well how do you know there isn’t impurity transferred from one to the other in this way, and they looked at each other and looked at me and said, we didn’t know they were using the same tools. Because you actually set something up and you can’t, unless you’re there all the time you can’t be sure. I can still remember actually one of the people, I went into the lab, this was much earlier when Harry Bennett, was his name, he was working with George Starkiewicz on, at that stage George was making cadmium telluride, this was when we were starting getting interested in solar cells and cadmium telluride’s a very good solar cell material. And I saw Harry taking a piece of tellurium and moving it from the balance where he’d weighed it to the boat, and I said, ‘Harry, you are handling the tellurium’, which actually was quite dangerous later on because it gets in your skin and causes a form of arthritis which can be very serious, but we didn’t know that at the time. I said, ‘Harry, you’re handling it’. He looked at me, he said, ‘So what Cyril, I washed my hands before I touched it’. [sighs] Yeah. You have to watch each stage of this. I caused – did I mention Bell Labs?

[1:51:00]

*Well you’ve mentioned Bell Labs but I don’t know if this is the same.*

Did I mention my visit to Bell Labs when I caused a lot of problems? We were comparing notes with people and they were interested in gallium arsenide. This was quite early on I suppose, where I pointed out that they were actually doing their work in more or less a pseudo-clean room, it wasn’t as clean as the rooms we used and we took a lot of care at each stage, damn it, it didn’t seem to work but at least we spent a lot of care on this. And they denied, they said that their conditions were perfect in everything and I sort of looked around, I said, ‘But look, this is a
normal room, you’ve actually got fume cupboards and everything here but you transfer things between’. And they said, ‘Yes, so what?’ I said, ‘Well, you’ve got a normal ceiling. You’ve got to think of this as being a kind of shower of dust coming down on your things, although you cover them, you can’t stop it from getting in places’. They said, ‘Oh no, no, no’. They denied it, but later I heard that immediately I’d gone they ordered a false ceiling to be put in, of plastic, because they knew that was happening. But, you can take things for granted, you get into a sort of condition where you watch for things and you are very careful about what goes on and it’s not obvious sometimes, the kind of thing that would happen, and you can’t always prove what is going on, you try and solve problems. It was much later on that we got a problem with putting gold electrodes on indium phosphide and the gold was disappearing and we never knew what happened. I think, I obviously made some suggestions before I went away and about three months later I realised nobody had mentioned gold in indium phosphide. I said, ‘How did you cure the gold problem?’ They said, ‘We don’t know, it went away’. And that happens too. You can’t always know why something is happening or how to stop it happening, but you do your best very often. There was one structure that… later on we were working with devices – this is appropriate at this time, though we’ll come to the actual background later on – where we had a sample of gallium arsenide which was on a substrate, which was doped heavily. So that was going to be one contact and the second contact was a tiny tin dot that we put on the top and we discovered that if the tin dot was negative the device worked. If the tin dot was positive – now this device had no junctions in it or anything, it was just a piece of gallium arsenide that as far as we were concerned was isotropic - and you put the tin dot on and if the tin dot was negative it worked fine, if the tin dot was positive it broke. And I mean this didn’t happen once, it was automatic, it happened. And there was a rule, that whoever was working, they were allowed one failure through being careless. After that they were denied access to the devices. It applied to me too. And we no longer got failures because people knew that the tin dot had to be negative. We never knew why. Still don’t know why. I have no idea. We got away from tin dots later on, as we’ll come to, but at that time that was the standard way in which we made devices, the standard way in which everybody made devices. And everybody knew the tin dot had to be negative. So that was okay in industry, you made a mount where it was clearly labelled negative and put the thing on, but in a lab you make your sample to do this and you don’t look or you’re not careful and your tin dot becomes positive and, damn it! I will say that the rule about you’re only allowed one was honoured in its… in the statement rather than the observation since you didn’t know how many devices people had broken anyway, but occasionally you got an
expostulation coming from somewhere with some abusive comment and you felt fairly certain that they had actually put the voltage wrong on the sample. But we never knew why.

_Are there any other uncertainties in this sort of work on a practical level?_

You can’t always solve every problem, nor do you try to, because you can spend an awful lot of time on solving problems which you may get round in totally different ways. I mean you can abandon a procedure because it doesn’t work, because you’ve got another procedure that may not be quite as convenient but is more reliable.

_Time for lunch I think._

Yeah, I think it’s a good time to go to lunch, with the invention of the semiconductor laser.

[end of Track 11]
I was wondering, before we go into the semiconductor laser, if you could just give me a very brief two minutes…

Okay.

...idiot version of what a semiconductor is and what it does.

Well, the word semiconductor doesn’t really describe what it does, though it does indicate that it is not really a conductor, though it can conduct quite well. All metals are conductors but there’s very little more they can do that you can’t do much electrically with a metal as a conductor. You can do some things, but essentially it is going to conduct electricity, depending on exactly which metal you have got. A metal like copper or silver conducts electricity extremely well. A metal – I’m trying to think of a metal that doesn’t conduct as well – but nickel of course is a metal, but it won’t conduct as well, it does other things. And there’s always the property of magnetism that you get from some metals, which is very interesting. But semiconductors have different properties and as a result they have more applications and the real point about a semiconductor is not that it’s half a conductor, because its conductivity can be quite high, but because you can control the conductivity. You can control the conductivity because you can add impurities to the semiconductor which itself give you the electrons. A pure semiconductor of some types will not conduct at room temperature at all well. Others will, but those of most use like silicon, germanium, gallium arsenide, cadmium sulphide, materials like that, will not conduct at room temperature unless you do something to them and what you generally do is you add impurities and you know the effect that those impurities will have. There are two types of conductivity that you can get which again distinguishes them from metals, that you can have the normal electronic conductivity that you have in metals, but there’s also another type of conductivity that you can get which essentially is the absence of electrons, not the complete absence, but think about a sea of electrons. [interruption]

[break in recording]

[02:30]

Sorry, you were talking about electrons.
There’s another kind of conductivity that you can get. If you think about a sea of electrons, you can get a complete sea of electrons in a semiconductor if it’s pure, and then you can think about identifying what is happening in that sea. It’s actually very difficult to see any motion happening, but all of the electrons may be moving, you can’t identify it because there’s no point of reference. Now take an electron out from that sea and you can look at the absence of that electron which you can think of as a hole in the sea, and now the sea as a whole can be moving and you can watch that hole moving. The arithmetic of that motion can be described as the motion of the whole sea, or in fact we discover you get exactly the same result if you forget about the sea and you think about the hole moving, provided that you say that the hole is a positive charge, whereas you know that really all of the electrons that are moving are a lot of negative charges. It just works out no difference that the effect is exactly the same as a hole moving in the opposite direction. As a result we can describe semiconductors as one of two types. We can say that those where we’re thinking about the individual electrons moving as n-type for negative, because that’s the sign that the electrons have. But the other type where it’s the sea that’s moving, but in fact we’re describing it as the hole, we call the p-type. That of course indicates that we have a difference in the semiconductor from what we have in the metal, because you don’t have that circumstance arising. We get more things happening as a result because now we can think of what happens when we put some n-type semiconductor next to a p-type semiconductor, and now we get very strange things happening in the body at the barrier between them which we call an n-p junction. And it’s that n-p junction that is the foundation of many of the applications of a semiconductor. That doesn’t mean to say that’s the only thing we can do, because we also can control the passage of the electrons or the holes in the semiconductor by the electric fields that we apply to the side and if we apply the right field at the side, if you can think about a body in which carriers are moving, be they electrons or holes, if we apply a transverse field, we can cut off that current and that is the basis of most of the chips that you see around these days.

[06:00]

Where does the semiconductor laser come into this?

Well, I don’t know that the semiconductor laser comes in because it didn’t come in for many years. The semiconductor laser was a realisation on the part of those people working on semiconductors, that if you can do anything in other materials you ought to be able to do it in semiconductors. It’s not actually true but it’s a kind of ambition. And when the laser was
invented in 1960, it was a laser that was based on light being amplified within either a gas, like helium, or a crystal solid, a glass or a crystal. But the process by which the light was amplified was quite different from that in the semiconductor. Remember that we had said we’d already got actual light emitting diodes, though they were infrared of course, but they were effectively emissions of light electromagnetic energy, photons, that are smaller in energy than those you have in the visible, but we’d made devices where you could convert the current that you were feeding into a p-n junction into photons being emitted from that junction. Now, that is a process known as spontaneous emission, but there’s another process called stimulated emission whereby you actually get a photon emitted from a semiconductor when another photon comes in. You’ve obviously got to provide some energy but the transition can be shown to be possible, and indeed it comes directly from Einstein a long time earlier, that you don’t just need your power coming in from your battery source or your power supply, that provided there’s some energy there, you can actually get two photons coming out at the same time. And the power you can put in can come optically so you can do exactly as you do in the crystal laser, pumping your semiconductor laser with light or with electricity. Now the first lasers that were made in the semiconductor world were by taking a p-n junction and the p-n junction in the form whereby it emitted infrared radiation, which we’ve described earlier, in other words, it’s very heavily doped, you bias in the forward direction the low current – the low resistivity direction – so that the electrons are fed into that region in the middle and the holes are also fed into that region in the middle so there’s a possibility of them recombining there and giving off radiation. That will give you a light emitting device. But now you arrange that the light cannot escape easily from the device. It’s reflected back and that reflection will be pronounced at just one wavelength or one frequency if you know what you are doing. So as a result the light at that wavelength builds up and builds up very rapidly because it’s amplified, whereas the light at the outside frequency outside that waveband will stay at a very low level. So almost all of the electrical energy that you’re putting in will now be converted to a very narrow wavelength emission. But of course what I’ve said actually hides a number of problems. How do you ensure that you are first of all converting your radiation, converting your energy efficiently into radiation and at the same time ensuring that you are only amplifying the radiation at one frequency. A number of people were trying to do this in the early 1960s, 1961 and 1962. It was a French group that showed first of all the theory of what you were trying to do and then a Russian group at Leningrad said they thought they had seen the first signs of a semiconductor laser. What they had seen was that the radiation coming out from an ordinary gallium arsenide light emitting device was narrowing, the wavelength spread was getting narrower as you drove it harder and then they said, what we need to do is to form a cavity,
a resonant cavity so that just that one frequency is amplified. And what they meant by that was
you have to make a structure whereby that light is reflected backwards and forwards between two
mirrors, which is the way in which it was done in the ordinary gas laser, but here it was more
difficult to arrange because it had to be done on a millimetre scale, perhaps two millimetres. This
of course was possible but somebody had to work out exactly how to do it. The group that first
found out how to do it was at an industrial research laboratory in Schenectady, the General
Electric Research Laboratory, where the leader of the group was a very gifted scientist called Bob
Hall and he showed that if you actually took a cube of gallium arsenide, that automatically
because gallium arsenide has a high refractive index, the light that was generated in the junction
would be reflected backwards and forwards inside that junction. So you now have to think of this
as a transverse structure. If you’ve got a cube, the top and the bottom are where you apply your
electrodes and you put your power in. Your junction is parallel to that top and bottom surfaces
and of course is a very narrow region and that radiation will be reflected backwards and forwards.
Of course it can go out in all four directions, but you can arrange that it doesn’t go out in the third
direction by roughening the surfaces slightly. So you’ve now got a resonant cavity and you don’t
have to actually specify that spacing very accurately because the light will do that for you, you
will get a multiple of reflections at the wavelength of light, but you will see that when you drive it
hard that you get light narrowing and then effectively just one wavelength coming out, and it will
come out exactly at right angles to that face. Of course that again describes a multitude of sins as
to how do you actually get all that to happen at the same time, because there are so many
competing loss processes that you will see in the structure and the first is that you will get some
heating and also you have to drive the device very hard. So to ensure that you reduce the heating
you cool the whole structure to liquid nitrogen temperature and that ensures that the efficiency
will be very high, that the other loss processes are minimised. And next you will drive the device
in short pulses. You have to have a short pulse generator because if you drive it at the currents
that’s necessary for this simple structure you will blow it up. And this was done in September
1962 by Bob Hall, but as I said everybody was interested in doing this and another group at IBM
under a gentleman called Marshall Nathan also did this with a different structure, they had a
circular structure, a different mode structure but again they produced a laser which you could see
by the narrowing of the wavelength spread and the directionality that you get, they were about ten
days after Bob Hall and then another group related to the Hall group at another GE Laboratory in
Syracuse New York State under Nick Holonyak, they actually used a slightly different material,
by alloying gallium arsenide with phosphorus making a material we call gallium arsenide
phosphide they were able to get radiation in the red because the gap that we’ve spoken of earlier
between the valence band and the conduction band is raised when you add phosphorus, so you’re moving the photons that are generated into the red region of the spectrum. So the first visible injection laser – we call it an injection laser because we’re injecting electrons and holes into the region where they’re going to recombine – this was the first visible injection laser, which was made [16:10] I think in about October 1962. After that, there were various groups, a group at the Lincoln Laboratory, a government laboratory that was part of MIT, also produced a laser in early, probably November, they published in December, and our group in Baldock produced the first laser outside the US in December 1962. And I used to say that we were the first, we produced the first laser in north-west Hertfordshire, which was true. It did disguise some of our achievement because it wasn’t easy to make the laser. Other laboratories followed, obviously later and in Russia they produced lasers the next year and almost anyone was able to produce lasers after that.

[17:10]

*Why were you interested in making a semiconductor laser? You said everybody was.*

It was an achievement, it was an interesting thing to do when you had confidence that you would find a use for such a compact, efficient source of radiation. And indeed, the proof of the pudding is in the eating because now lasers are critical in fibre optic communications, and it may surprise some people, particularly some young people, to think that they’re essential in CD players. So in fact, although the injection laser came two years after the gas laser and probably had less publicity then because of that, they’re used much more widely than the other lasers. They’ve never been quite as perfect a laser. The actual purity of the radiation that you get from gas lasers and some crystal lasers is higher than you get from semiconductor lasers. But semiconductor lasers are so useful because not only are they extremely efficient, and now of course we get them working easily at room temperature and above, though that needed quite a lot of sophistication and structure which was not available to any of us in those early days, you also can modulate them, you can turn them on and off very rapidly and that is why you can use them in communications because the secret of good communications as we all know now is wide band width and wide band width equates to very fast operation and the way in which the laser works makes it much faster than an ordinary LED.

*What sort of applications did you have in mind?*
None, really. We made it because other people had made it and we couldn’t be behind. It essentially was a demonstration of virility that you could do it. Then we started doing some things with it. We showed that you actually could get such a concentration of energy locally that you could burn paint. One of the things that we did is we had a metal plate, tiny metal plate, and we put paint on it, brushing Belco black paint, and then we focussed our laser on it and could see tiny white hot spots where we burnt the paint off. And you could write a line, you might even be able to write your signature if your hand wasn’t shaking too much. I don’t think we ever succeeded in writing a signature, but we did write a line. We had nothing in mind really, though we had at the back of our mind that you could communicate. We knew that people could communicate over light beams and we thought we could communicate and we knew that there was a wish at the army laboratory in Christchurch to actually send pictures over light beams, because they thought that would be useful because it was a secure way of communication. It was well known that radio communication could be intercepted and people obviously put various codes on it to keep them secret. But if you had a light beam it was much more likely that nobody would be able to see it if you sharply focussed it, so you had more security. So there was some interest there, but I can’t pretend that we had something in mind when we made it and in fact this was true of most of the world and for some years laser was described as a solution in search of a problem.

[21:10]

*How difficult is it to actually make one? This first laser, how do you make it?*

Well, you take a piece of your semiconductor, that’s gallium arsenide, and here it doesn’t have to be that pure because one side is going to be doped, so you’ll take a piece of gallium arsenide that will have perhaps $10^{17}$-$10^{18}$ electron impurities, so it’ll be n-type. And then you diffuse some zinc into it and zinc will make it p-type. And that gives you a junction and that is the easy part, diffusing the zinc in. You have to know what you’re doing because it has to go in a certain distance. And now you’re going to put your contacts on. The more difficult thing is to make the mirror surfaces and this is where if you understand what is happening you can do it quite easily because whereas in the other lasers you have to make the mirrors and make sure that the laser, the mirrors are exactly parallel to each other to make the cavity, here nature will do it for you, because it is a cubic crystal structure and you can cleave two surfaces in a cleavage plane and they will automatically be parallel to each other because of the crystal structure of gallium arsenide. So you use a razor blade and with some skill you hit it and you made it from a slice of
gallium arsenide that perhaps is a millimetre thick, you hit it, you make one surface, you hit the
other side, you get another neat surface and you’ve made two surfaces at right… at right angles to
the electrodes where you’re going to put them on and they’re going to be parallel to each other.
You then simply put your electrodes on or you put contacts on to the two electrodes, and Bob’s
your uncle. Then you’ve got to find a way of cooling it, you’ve got to put it in a Dewar flask to
cool it with some windows so you can see what’s going on, and you cool it to liquid nitrogen
temperature and have a pulse generator that will drive it hard.

What does it actually look like once it’s there?

Looks like a tiny little chip of black stuff. Looks like nothing really.

What about everything else connected to it?

Well, the everything else connected to it, you’re going to have, usually a tin dot on one of the
surfaces, you’ve probably evaporated some contacts on the two surfaces and they’ve got to give
you a good connection. You’re going to now make a connection for your wire to be soldered on,
so this would be something like indium or maybe tin that you will melt on to the surface and put
your wire in and that is a relatively easy part of the process. It’s the preparation of the device
itself which is more difficult. But when you’ve learnt how to do it you can make hundreds of
them with no problem at all. You design a very simple clip for holding it.

[24:50]

Where did you find out about the other laser developments in the American labs? How did you
find out about it, sorry?

They sent us pre-prints. They were anxious to tell us because they wanted us to know they’d got
there first, curse ‘em. ‘In Dnepropetrovsk my name is cursed when they find out I published
first.’ Er, yes, we were, we didn’t have to wait for the publications, they all sent out pre-prints.
Now of course it’ll be online but then you actually got something through the post that told you
what they’ve done, yeah.

How accurate does this cutting perfect…
It doesn’t have to be…

…*parallel surfaces*…

It doesn’t have to be terribly accurate. I mean we knew… well, you know first of all if you take a slice of single crystal gallium arsenide, say a millimetre thick, and you just break it, it will break along a straight line and will look highly polished, it will cleave, it is a cleavage surface. And there’s absolutely no problem, no cleverness in doing that. And certainly you can do it where you want it by just taking a razor blade or a screwdriver and just putting it where you do it and giving a slight tap and the material will break along a crystal axis. And fairly obviously that will happen in the other direction too, parallel to it. You don’t have to do it that way, you can actually polish the material just as one polishes glass. You can put it in a jig and just use a normal polishing technique that you will use for getting an optical surface.

*And how big is – I’m still picturing what this thing actually sort of looks like sitting there on a bench in its entirety.*

Well, I described how… The size of the chip will be about two millimetres by two millimetres by perhaps a quarter of a millimetre. It’s quite thin and quite small and you will have two wires coming out from it; one from the top, one from the bottom, and you have got two surfaces that are about two millimetres by a fraction of a millimetre, well maybe it might be a bit less than a millimetre in the other direction, and the light is going to come out from the middle of one of those faces. It’ll go in both directions, but you can stop that happening by reflecting it back again. You can be more sophisticated and put an anti-reflection surface on one of them if it’s not too anti-reflecting so you get some light coming out, or you can put a gap in one of them, you can actually scribe that shiny surface so that light comes out from it rather than being reflected.

*And this is all sitting in a cold vessel of some kind?*

Yes. It’s on a cold finger in a Dewar flask in front of an optical window so that the light can get out.

*And then wired up to the pulse generator on the outside?*
Yes, yes.

*Right.*

And it doesn’t need to be… the pulse doesn’t need to be that narrow, probably a microsecond is fine. All you’re doing is ensuring that the device doesn’t get too warm when you drive it hard.

*How many of you did it actually take to build the thing?*

Well, it depends where you start.

*Let’s take the first one.*

Somebody’s got to make the gallium arsenide and that usually is one specialist, then somebody else has to look after the diffusion of the zinc into the gallium arsenide which may well be the same specialist, and then you’ve got somebody to do the cleaving and the electrodes, which might be the same person doing it or it might be somebody else, the experimentalist who’s going to do the measurements might be taking over. The experimentalist will do the mounting. The mounting is usually putting the device after it’s been cut up in a special clip that you’ve designed which will, a spring clip, which holds it and then it can be held in the Dewar. So I would say two or three people would be involved in growing it and measuring it.

*Do you remember what happened when it first got switched on?*

We knew what should happen. I don’t remember how soon it was that we did it. It can’t have been that long because I know that we showed it to David Fishlock of The New Scientist early in December, so it appeared in his Christmas issue, and I knew we hadn’t started working on it until late November. So it wasn’t that difficult, it’s one of these things, once you know it can be done then you can do it. It’s believing it can be done that’s the important thing. It’s a bit like the image intensifier that we mentioned earlier, that once they knew someone had done it, they were able to do it, even though in fact the first information they had was misleading and it hadn’t been done, but by believing it had been done they then worked out how to do it. Now this one you were certain that you knew how to do it. What we had to decide was, did we do it the GE way or
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the IBM way, and the GE way seemed more straightforward so we tried that, which was basically
the resonant cavity done as a parallel [31:40] surface, what we call a Fabry-Perot etalon.

You mentioned David Fishlock of The New Scientist, how did he come to be involved with this?

He was a good journalist, he had his nose to the ground and he knew what was going on. There
was no secret that people had made an injection laser, this was being published and everyone was
interested in what could be done. The laser was good news, most people felt that this was quite
an achievement to be able to do this. So we’d had the crystal laser and the gas laser and people
were improving that all the time and coming up with new gases, new ways of doing it, new
powers, all that kind. Once it was in the news that someone had done it with gallium arsenide I
suppose it didn’t take too much of a genius to come and look to us, because we were understood
to be the home of gallium arsenide in Europe and they would want to know what we were doing
and there was no secret about it that we were trying to do it and intended to do it. And in fact we
showed the laser at the physics exhibition which was annual. I think it was held at Alexandra
Palace and later on it moved to the Horticultural Hall. I don’t know where it was at that time but
it either was the Alexandra Palace, though I have a sneaking feeling it was the Horticultural Hall,
and we showed people this. And there was a slight furore and I got into a minor trouble over it
because I was cornered by two reporters, one of whom I remember came from The Daily Mirror.
I’m not sure where the other one came from, I think it was The Daily Mail. And they obviously
were used to working together and one of them would ask you the questions very rapidly and
develope from the questions while the other one took notes and then they would change roles in
doing this. And they wanted to know really why was this being done in a defence laboratory,
what was this intended for. Now, you have to remember that this device was emitting infrared
radiation, it was gallium arsenide, it came out from a Dewar, but nobody would have been
impressed with that at an exhibition because they couldn’t see it, so we naturally had an image
converter which converted the radiation from the laser into light that you could see and the
phosphor we were using gave out green light, that is not unusual, it was a zinc sulphide phosphor.
So you could see the pattern coming out from the laser and indeed the pattern was quite
interesting because the laser did not work effectively along the whole front of the p-n junction, it
was blobby, there were three or four regions along the junction where there was more radiation
coming out quite intensely and others where it was much less and some where it was just the
spontaneous radiation. But it was an interesting picture. Anyway, when I got back home and
went into the laboratory the next day, the superintendent, Robert Sutton, asked to see me and
more or less said, ‘You’re responsible for these headlines in the paper’. I said, ‘What headlines?’ and he showed me. ‘Your house will be lit this way.’ And he said, ‘That’s really stupid, having your house lit’. I said, ‘Yes, particularly since it’s infrared radiation which you can’t see’. He said, ‘Well why didn’t you make that clear?’ I said, ‘I had no alternative’. I said, ‘Would you rather have had us using the laser to communicate with our nuclear submarines underwater?’ He said, ‘That’s just as ridiculous’. I said, ‘Yes’. But that was the choice. Either we were doing it because our laboratory wanted to communicate with our submarines underwater or else we wanted to light our houses with this radiation. That was the choice and I chose that one. He said ‘All right, I expect that one’s the least harmful’. And indeed, I then started getting telegrams – in those days we had telegrams – from the people who supplied our gallium, a company called Alusuisse, obviously in Switzerland, and the telegram said, ‘Understand you have new application for gallium arsenide. Should we increase our production?’ And I telegraphed back saying, ‘Don’t believe everything you read in the press’. That was it. And naturally we carried on working, as did the other people in the consortium, in trying to produce lasers that worked at higher temperature and lower current, and the two things went together, and there was steady progress on that.

When do real applications start coming in for it?

I think it was a good five years, if not longer, before. There could be only a minimum of applications while it had to be cooled to seventy-seven k. There were certain devices, particularly some infrared detectors that were being used in defence, that you could cool and we dealt with the missiles using lead sulphide, which were cooled. So there would have been some applications there where people didn’t worry about the cooling, but there would have been nothing of very much significance until we had raised the temperature. That progress came from two groups, one in Leningrad and the other in Bell Laboratories, where they showed that there were more complex ways of making that p-n junction that actually meant more of the carriers were recombining within the junction region and the light was better constrained to stay within the junction region and this and other technologies had been used so that now it is normal for all lasers to work at room temperature and above and there is a characteristic wavelength at which they will work. In addition you can do other things, changing the wavelength slightly to make best use of transmission. For instance, in optical fibres there are certain areas where the
transmission is much higher than in others and you will tailor your device so it works there and that we will come to later on when we talk about band structure engineering.

[39:40]

*Other than the semiconductor laser, what else were you working on at Baldock in this period?*

Well, we were still interested in trying to get microwave radiation out and just about this time a British scientist working at IBM in the States, called Ian Gunn, had discovered a very strange effect in gallium arsenide. Ian we knew very well, he had worked for Elliott’s in the UK and we’d known him at conferences and his virtue was he was a genius at getting very fast pulses and things, and he had made an equipment for giving extremely fast pulses, much better than the state of the art. Essentially he used a bouncing ball technique where he had a metal ball that bounced up and down and each time it made a contact you would get a pulse out from it. And he’d applied this technique to look at germanium because he was interested in the electron bunching effects that he could get in germanium. But he’d also been interested in acoustic wave amplification in various materials where sound waves could pass along the surface of materials and you could get them amplified and make some devices work that way. And he had taken his samples of gallium arsenide and had shown that he started getting very fast pulses out from when he worked above a critical field. Now, he used bulk pieces of gallium arsenide but he used thin pieces and he showed that when he got fields of between 2,000 and 4,000 volts per centimetre from the pieces of gallium arsenide which were uniform pieces of gallium arsenide, he got these instabilities and the oscillations. Now you will say well, that was the effect you predicted a year earlier, and so it was. But Ian Gunn refused to accept that. He said it was an amplification of optical modes and he went through a complex theory which he said showed within a factor of three that he would get these effects. He wasn’t ignorant of what Brian Ridley and Tom Watkins had done and what I had done, but he said that he had ruled our explanations out because the electrons were not energetic enough at lower fields to give these effects. Now you could show conclusively actually if you read either of our papers, that the electrons did not need to be very high, the temperature [interviewee correction: ‘the electrons did not need to be at a very high temperature.’]. In fact there was great controversy as to why Ian Gunn did not see immediately that the effect he was observing was the effect that we had predicted. He claimed Tom Watkins had been to see him and he’d convinced Tom Watkins that it wasn’t that effect. How he could have done that was almost impossible to understand because Tom was a clever person and he would never have believed that the thing was operating as Ian was predicting. [43:35] There was a lot of
controversy that almost was racial or national in that the Americans were accusing of Britain, of not really believing the British theory, which is curious when you follow it because obviously you had me on the gallium arsenide, you had Ridley and Watkins on germanium strain – all the physics was there, in detail, it wasn’t just us saying that this would work in this way at that field, we had all of the details worked out and here was another Brit saying it was something totally different. There was also at that time considerable enmity between IBM, which had set up this very posh laboratory in Yorktown Heights, and the Bell Labs at Murray Hill who were the originators of the transistor, and they didn’t get on too well with each other. In fact it was said that if somebody wrote a paper at Bell Labs and they quoted in the references an IBM paper, they had to get special permission to include it. But if they had references from any other laboratory in the world that was fine, but they had to get special permission to quote IBM and vice versa. They did not get on well with each other. And Bell Labs went to some trouble to actually do experiments to prove that Ian Gunn was not just misguided, but I don’t think it’s exaggerated to say he was malign in deliberately ignoring what was being done in the UK. Interesting because this was all being done in the States. Meanwhile, Herb Kroemer, who had been at the Post Office Research Laboratories in Germany and done some excellent work on semiconductors, a very respected man. He was now at, I think, Santa Barbara on the west coast of the US, and he wrote a very carefully composed letter in which he set out the evidence – it was only a letter – but he said if you take Hilsum’s predictions you get this happening at this field and this field is more or less exactly where you’ve observed it. He got a spread, but the spread was easily understood by the imperfections in the gallium arsenide. It was quite a feat to get it to work on any of the bits of gallium arsenide, never mind getting it working reliably. And Kroemer said that the average field that you’re getting is very near 3,000 volts per centimetre that is predicted. Your point about temperature is just not valid because Hilsum has shown that this all works at an electron temperature of a thousand. Ian Gunn had had a measurement of the noise in the electrons which showed what their temperature was and he claimed they were too cold to do this, whereas both Tom Watkins and Brian Ridley and I had shown that the temperature did not need to go up too much before you got the electrons accelerated. And then he went on to say, but in addition you have this separate work of Ridley on domains. Now, Brian had, I think it was after he’d moved to Essex, it was just at this time, he’d done an analysis of what happened in the instabilities and had shown theoretically exactly what I have told you, that when you go into this negative resistance region what happens is that the material breaks up into two parts; a domain which takes in much of the voltage, it’s a high field narrow domain, as a result of which the rest of the sample is operating at less than the critical field. It does this automatically and that domain will then move
through the sample. And this is precisely what Ian Gunn had observed. Ian came in for a lot of abuse after that with a lot of people. It didn’t stop them from calling the device a Gunn diode, though in fact people started talking about the Ridley-Watkins-Hilsum mechanism, abbreviated to the RWH mechanism, and some of my friends started calling them the Gunn Hilsum effect. But most people then talked about it being a Gunn diode and I can say that I am a person who made their reputation, much of their reputation through a device named after somebody else. And they’re still called Gunn diodes, but everybody knows how they work, there’s no doubt, and in the end Ian had to admit this. But in fact the feelings ran very strong for many years afterwards, many years afterwards. And Bell Labs published a paper, I suppose it was ’63 or it could have been ’64 – probably was late ’63 – where they showed that when you applied pressure to the device that was oscillating, we knew that if you applied high pressure those levels changed. I pointed this out to you, it’s as though the whole thing is tilting and when you apply pressure the high conductivity levels move above the low conductivity levels. And indeed, you can say that what you’re doing is you’re converting gallium arsenide into something similar to silicon. When you do that, at just the pressure you expect the two levels to come equal, the oscillations stop and it was conclusive that what he had observed was our effect. He didn’t comment on this. He did write some papers as to why he didn’t believe it, but it was very difficult to understand why he had resisted it for so long. Many years afterwards I was at a conference on high field effects in a place called Denton in Texas where I was asked to open the thing. I think it was 1978 by then, I’m not sure when it was actually, but it certainly was some years afterwards. And I gave a talk which was called ‘A Look Over the Shoulder’, which was basically looking back on those early days and how it had all happened and there were other very notable people present from the American semiconductor scene. And there was one person from IBM who was nothing to do with Ian, nothing to do with Ian Gunn at all. He was British actually, his name was Peter Price, he was a theoretical physicist. And when he gave his talk on something and it was question time, he was attacked unmercifully by the Americans on the IBM behaviour over this and I couldn’t understand it. I was quite relaxed about the whole thing, as was Brian, because I mean we knew what he discovered, we didn’t care, I mean we knew that this was happening and we predicted it and we were very happy, I mean it had happened on the material, in the bulk material and at the field at which we’d predicted it. I mean Brian was happy that he’d predicted the effect, I was happy I predicted it in gallium arsenide at this field and now we could go ahead and try do some things. So we were fairly relaxed, but the Americans were furious about the whole thing and this had persisted. And Peter, and who also was British, curiously enough, was saying he had nothing to do with this, he was in a different bit of IBM at the time, he didn’t know what was
happening, why were they attacking him? They said we’re not attacking you, we’re attacking IBM. It was all very surprising and, I suppose, pleasing that they were upset, they felt in some way that the Americans had been let down because of this controversy, and it was difficult to understand, there’s no question of that. It wasn’t as though IBM was going to patent it. They tried, but you couldn’t patent it because it was a natural phenomenon that occurred in a material, it would be very difficult to cover it. They tried, but also IBM weren’t going to use it, they weren’t going to exploit it, they never did try to stop anyone from exploiting it by asking for licences or royalties. It clearly had been predicted, so how could you do it. So it’s a slight mystery. But, it did mean that gallium arsenide had another effect, [59:00] so suddenly we had gallium arsenide changed from being a material that was of interest that we were going to make a red hot transistor in some time, into a material that had two clear different effects that you couldn’t get in silicon. One was the semiconductor laser and the other one was the transferred electron device. And that of course was of great encouragement to all the people working in gallium arsenide because although we couldn’t quite see how we were going to use it, we knew that we had found a potential in gallium arsenide which justified our research. So we could carry on doing what we were doing and got a body of strength coming from that that was general in the community. So it did mark quite a change. It also started a change in semiconductor research in that people could see new things that they could do, both in the optical effects that you had in the semiconductor laser and in the high field effects that you could see. So you could see a change in the stream of papers coming out and in the groups that were interested in the material. It took some time but you didn’t feel you had to apologise for working on gallium arsenide any more. So they were halcyon days, except of course with what was happening in Baldock. So we had these two things happening and it was, before I get on this, personally I was beginning to benefit now by the higher visibility on gallium arsenide and, as I have said, by the unmerited credit I was being given for the progress that had been made in the manufacture of the material. But we were learning much more about how to make it and its properties and what happened with impurities and things. I was becoming more prominent in the semiconductor field as a result. I can’t say that I objected to this, but I was conscious that I was getting credit for work that other people did and for the work of my group. But we were doing a lot of work on trying to understand what was going on in the material and in semi-insulating gallium arsenide as well, and one of the things we realised was semi-insulating gallium arsenide was a very good substrate for what people wanted to do. I have said that it was very important to get the crystal structure of semiconductors right because then you got defined properties, but when you wanted to grow crystals it was wasteful and difficult to grow bulk material. What you would like to do was to grow a layer and now
people were learning that you could put down layers of semiconductors from the vapour phase, that you could actually condense layers of material, be it germanium, gallium arsenide, silicon, indium phosphide, almost anything you could put down if you had the right crystal substrate and if you chose your substrate well, you could grow a layer that had the properties in the crystal that you wanted and one great virtue in doing this was that it was much easier to have pure material coming from the vapour phase than if you grew it in a crucible. That made some sense because if you’re melting something in a crucible, any impurities in the crucible are likely to go into the material – remember Spectrosil and the quartz – also applied to anything that people were using, even if they were growing silicon in a quartz crucible, which would have been difficult but was possible, or germanium, it still would take up some of the impurities that were there. But if you took it in the vapour phase that you could start off with those elements and because you were working with a vapour you got a much better control over what you were putting down, but you had to learn how to do that, how to purify the material, work out what was happening in the gas phase and also find a substrate on which you could do the deposition. Now the natural substrate would be the material which you were trying to put down and that would act as one of your electrodes, so that was okay. But if you were doing something like trying to make a transistor it was going to be more complicated than that, or a microwave circuit, and what you would like to do is put down the material at different places on your substrate and get operation in more than one device. But of course you had to have a substrate then that didn’t conduct. So what you wanted, if you were thinking for instance of a complex circuit in gallium arsenide, you wanted something that had the right crystal structure but didn’t conduct. And do you know what that was, it was semi-insulating gallium arsenide. Semi-insulating gallium arsenide was going to be the structure on which you put things down that you actually could deposit your circuits on. And I seem to remember that I did actually patent that. I got that through our patents people, with jointly some of our other people like Mike Coupland. But our patent agents would never – I was still in the Admiralty, remember, not the Ministry of Aviation – would never do anything to actually push that through. It’s a long time ago so the patents would have expired, but I can say that semi-insulating gallium arsenide made in a more controlled way nowadays, it’s done by iron doping, is actually a building block on which people do make more complex microwave circuits. So it takes time but still it comes through.

*Why this reluctance to patent at the Admiralty?*
I’ve told you, that they knew that it would give them more work to do. They couldn’t see that, they never exploited their patents, they couldn’t see that the Admiralty was going to make any money out of it. As far as they were concerned it just gave them more work without any benefit. You could argue that we were going to be developing through NRDC, the National Research Development Corporation, but they weren’t too far-sighted in what they were doing. They’d never… they’re much better now, I will say what’s come out of NRDC after a long period, they’re now doing much better in their exploitation and they no longer have the rights in research that’s developed under government funding, but in those days they did have. It was a good concept but never quite worked. So, there we were, we knew we could make these materials and I was, as I say, getting a reputation and indeed in 1964 I actually was giving one of the few invited talks at the International Conference on the Physics of Semiconductors, which was quite an accolade. I was invited to talk on III-V compounds and I talked essentially on the basic physics and what you could do with a variety of III-V compounds, including going into the band structure and electron transfer and all those things, that was 1964. The only problem I had is they chose my talk to be on the morning of the day after the banquet, which was in the Hall of Mirrors in Versailles. It was a French conference and the people had actually talked to – no, it wasn’t in the Hall of Mirrors, it was the Orangerie. They wanted to have the dinner in the Hall of Mirrors. The International Conference on Semiconductors was held every other year and there was great competition between the different countries to ensure that their banquet was going to be better than the banquet that had been held the year before. We’ll come to some of the other conferences later on. But this one was to be in France in 1964 and the organisers wanted to have the banquet in the Hall of Mirrors, but to get permission to do that they had to go and see de Gaulle. And the story goes, and it’s apocryphal, it may not be true but I believe it was, they said, he said it’s a great compliment and of course, of course you can have your banquet in the Hall of Mirrors and it’ll be a magnificent occasion. And they all bowed and started walking out. He said, ‘Of course, there is one condition’. They turned round. ‘Condition mon General?’ ‘The only language spoken in the Hall of Mirrors is French. No English, no German’. So they had to have a committee meeting and they said, ‘Hm, well, how do we get people to speak no English?’ And they said, ‘Well the English will speak French, nobody will understand the French, but at least they will speak French. The Germans, probably yes, their French will be all right, they will speak French. What about the Americans? No way. There is no way we can get the Americans to speak French’. So they had to go back to de Gaulle and say, ‘Sorry, mon General, we cannot meet your condition, we do not think we can meet your condition’. And he said, ‘Well, you can’t have the Hall of Mirrors then’. Oh dear. ‘But you can have the Orangerie.’ And that was really
quite a night. I’ve still got the programme actually, which I was going to send to some of the Russians, a signed programme. And I can still remember, there were candelabra and footmen with white wigs and we didn’t all speak French, I can tell you, but we had a good time. And that went on to at least two o’clock and next morning at nine o’clock I had to give my invited talk and I had to apologise for keeping them awake, I was sure they would much rather be in bed, and I promised to let them down like a snowflake or a feather. But the talk went down all right.

*How many people actually turned up?*

Oh, most of them turned up, I’ll give them that, they did, they were quite interested. The topic was beginning to get more… you couldn’t ignore the III-V compounds then, people could see the potential of things, the things that it was going to be doing that were different from silicon and indeed, [1:06:30] silicon was moving from being the primary semiconductor on which you could do your physics to being the primary material for which you expect to make devices, that you felt you more or less understood silicon. There were some things which you didn’t quite understand but you’d been working on it for some years now. I mean germanium and silicon had been the subjects of research for, since the 1950s, the early 1950s, so you’d had ten years in which people were really working on it. Indeed, when Alan Gibson, remember from Malvern, was secretary of the 1962 conference in Exeter, he said he wouldn’t be surprised if this wasn’t the last conference we held since we seemed to know everything about silicon now, it was the best understood material. Of course Malvern was working on silicon, not on gallium arsenide. And people accepted that, that that was probably true, the physics of silicon was running out of steam. Of course they hadn’t had the high field effects and things coming in that they did later. So the III-V compounds were more or less an outlet for semiconductor theorists. So all of this was going very well and we were very happy with the way it was going. I’ll get back to the [1:08:15] semiconductor conferences when I want to talk about things that happened behind the Iron Curtain. But at the moment we were more concerned with what was happening domestically because all of this seemed to indicate that things were going well. There were things going quite well in Baldock anyway with other materials because John Allen’s group had been following up something that had been started in the University of Birmingham, a little bit unusually because as is obvious, most of this research I’ve described was done in industry or government laboratories. Birmingham had played around with gallium phosphide and had shown you can get visible light out from gallium phosphide and a group at Baldock under John Allen had worked on this and had shown you could make quite good red LEDs. They wouldn’t have had the speed that you could
get from gallium arsenide, but although we could get visible light from either gallium arsenide phosphide that obeyed the same laws as gallium arsenide by doping a little bit with phosphorus, and you also could do this by adding aluminium and getting gallium aluminium arsenide which Plessey had been doing, you could certainly get brighter light coming out from gallium phosphide which you shouldn’t have been able to do by the straightforward physics, but by adding certain impurities, particularly oxygen, which again has complex effects, you could get light out from them. So that group was working on gallium phosphide. And almost out of the blue Sutton made it clear that he wasn’t happy with the semiconductor group, that he couldn’t see what devices were coming out, we’d been there now for almost ten years, well it was about ten years, nothing had come out that had any applications and it all was a waste of time. This of course was conditioned by the fact that he never understood semiconductors. He wasn’t a physicist, he was really a microwave engineer. He understood how to make magnetrons, how to make klystrons, and he respected what you did with those. You could work out the oscillation frequencies and what was going on, you knew how to make the cathodes, you knew how to make a radar set. And essentially we had a big shed full of lathes where people were busy turning out copper and things and making quite large devices and this was something you could understand and it was being used in radar sets and since defence radar did not need that many devices they were perfectly capable of meeting their requirements just within Baldock. Then we had the laser being developed and there was a possibility that you were going to get things out from the laser which were useful, in particular there was a group working on a ring laser, which was a gas laser that had a triangle whereby the light went round and round and you could change the frequency by turning this, so it meant you could essentially make an accelerometer from it and you could use this to work out your position so this would be quite useful in submarines, in being a very accurate way of getting position. So he had groups that were doing things which were much closer to applications and defence applications than appeared to him to be coming out from semiconductors and he wasn’t happy. He was unhappy to the stage that he took away my group, gave it to a person who’d just about scraped a degree and knew nothing about semiconductors, but he had been very active in the neutron tube group, which was now coming to an end and was surplus to requirements and they were looking for applications of that, as I said, in cancer therapy which was proving quite difficult. So this person was at a loose end and he essentially gave him my group, which upset the group considerably and in an interview with me he said that it was becoming clear that there wasn’t room for both of us in this establishment and he had no intention of leaving, so would I kindly find somewhere else to go to. Now, he could do this. Remember, I had said earlier that he hadn’t a sympathy for organisational positions, that my rank in the Civil
Service was equivalent to that of a Principal Scientific Officer but I had the individual merit appointment of a Senior Principal, which meant I could take that anywhere as an individual merit, but not for an organisational post. But there was I sort of with my group taken away from me and put on making markers, gallium phosphide devices for film markers for the TSR plane, I think it was.

**TSR2?**

Yeah, the TSR2 I think it was. Which later came to nothing, but [1:14:35] he could get this group working. The group was horrified at all this, they didn’t know what to do. Occasionally I was summoned to come along and explain to somebody, I can remember an occasion when a well-known physicist from Bell Labs was visiting and somebody came running to my office and they said, ‘You must come, you must come. Ron is explaining to Jim from Bell Labs what a hole is’. Oh, yeah, hm. I came running along to get Jim away. And the whole thing was ridiculous. It wasn’t just me. He told Oliver Simpson - now Oliver Simpson was a person of some distinction and some clout, his father was the Head of the Met Office. Oliver was a very, very capable scientist – theorist and experimentalist – and he, I don’t know what happened, but he effectively was told that his time in Baldock was up and would he kindly go elsewhere. And he went to the National Physical Laboratory and ran the basic physics group for some time before he went to the Home Office centrally and became the Chief Scientist at the Home Office. So I mean he went there. Emlyn Rhoderick and Christopher Rose-Innes were both offered chairs in Manchester at UMIST and in fact the whole of the senior staff in solid state physics left and went to other places. The whole of it, except for John Allen, he was the only person. He was a PSO, he was the only person who stayed. He later went to St Andrews. So the whole of the work stopped. There were some other people in the microwaves who were interested in solid state, John Carroll who stayed, but the solid state people all went and that was everybody above Senior Scientific Officer, all the people of experience. The others were just left wandering, not knowing what the hell was going on. Naturally, relationships between me and Sutton were not great, then or even later and he got even more upset when I started doing well at Malvern, and in fact I didn’t know what to do. He said I should give up my individual merit and get a PSO job. I said I’ve no intention of doing that. I talked to NPL and they said they’d love to have me but they, politically they couldn’t take both me and Oliver, and if I waited they would probably find some way of doing it, but I couldn’t wait, I mean… And then I talked to Malvern and it was just at the time that Alan Gibson, who was their senior person working on semiconductors, was leaving and
going to Essex and I said would you be interested and they said yes, very much, come here. I said well of course I won’t be doing the same things that Alan’s been doing, I’m not a silicon person, I want to work on compounds. And they said oh, that’s fine, come here and do what you want to do. So that was all fine. The family was not happy. The kids thought it was terrible when we paid a visit there. Betty was reasonably happy, she didn’t mind, but it meant she would have to get a different job but she was willing to move and do that and that was quite a sacrifice because she’d now settled down and got a very good job at Hitchin Girls’ Grammar School after going through an interim period of supply teaching and various things. So it was good of her to just agree to move like that. But she knew what I was going through with Sutton. But when we took the kids over, it was a bad day, I have to say. It was Malvern at its worst. Malvern is best like this, it’s great.

_Sunny._

At its worst you get the mist descending from the hills and it’s often wet with things. And the kids burst into tears, they wanted to know why were we here, and when we said well, we’re thinking of moving here, they burst into tears. They thought it was awful. They did settle down in the end, but it was quite a wrench and professionally I didn’t know what the hell was going on. I had to talk to CVD about my contracts. They were not sympathetic with what was going on in Malvern, though Sutton had very close contacts with CVD, his brother-in-law, Paul Wright, Peter Wright’s brother, was I think then at CVD, probably Deputy Director. Yes, I think so, he later became Director. I mean they couldn’t understand what was going on. Well, that was an interesting stage. Would you like to turn it off for a minute?

[end of Track 12]
Right, so although things were going very well with me, as far as my job was concerned things were not going terribly well and I might not have fully appreciated it, being focussed on my contracts and the outside world generally in physics. But I became aware that Sutton was not as thrilled with what we were doing as we were and he made that clear in a number of ways. Now Sutton was a person who had very strong views and some of them were quite good things, he was a good thinker in some ways, but I suspect that his ability to do this had decreased as time had gone on. He certainly was the person who told me that – I think I mentioned before – that before you answer a question you try and work out why it has been asked because there are a variety of answers, particularly in the Civil Service. But he also was very single minded in certain ways. A good example is the one when the unions had succeeded in negotiating a reduction in the working week, the number of hours in the week, with headquarters. And this was going to be an hour or so a week. And Sutton immediately said to the union, well of course, what we should do is put back the starting time by a quarter of an hour a day, because people don’t come in on time anyway, they always come in late, all of them are a quarter of an hour late and some are longer than that, but we should put down the starting time. And the union said, no way, what we’re going to do is what’s been agreed throughout the Civil Service, essentially that people are going to stop work an hour earlier on Friday and have a longer weekend. Well there was nothing Sutton could do because it had been collectively agreed, but he was furious about this and insisted, and sent out a note to people, saying that they were going to have a shorter working week and it was going to be on Friday as agreed, but like this it meant they were contractually obliged to come in on time and he expected that everybody would get in on time, which I think was nine o’clock, it might have been eight forty-five. And people should know that he would personally observe this from his office window, which overlooked the front gate. Well, most people were a bit concerned about that, but others couldn’t care less. But Sutton did this and he was known to summon people to his office and take them to task, that they had to get in on time now. One of the people who got concerned was Harry Boot. Harry Boot was the inventor of the magnetron, he didn’t really need the job with Baldock, he didn’t need a job. He essentially was a gentleman research worker now because he had benefited from the royalties which EEV had extracted from the American government for their use during the war of the magnetron, which was quite extensive. The UK government had not itself asked for royalties because there was an inter-government agreement that they shouldn’t do that and free use of each other’s patents. But this didn’t apply to the use of the English Electric patents which had come from the magnetrons that they had used
with some variations on this, and they agreed with Harry, and I take it with the other inventors, that they would share in the royalties which were generous at that time. I know they were generous because Harry was able to buy a beautiful house ten miles or so away from Baldock and he also came into work in a Rolls-Royce, which as you can imagine was slightly unusual. And his attitude to his research was fairly relaxed but fairly brilliant too. He was no slouch and he understood physics and he had invented the magnetron because he understood what was going on, it wasn’t an accident. And he was working on lasers now and particularly on the ring laser, which is a triangular arrangement of three lasers which can be used as an accelerometer, it can detect motion and was going to find application actually in submarine navigation. Later on it became used in guided missile navigation as well, so Harry was happy with what he was doing, but he came to me one day and said, ‘Life is becoming a misery and I’m thinking of giving up’. I said, ‘What’s the problem Harry, isn’t the work going well?’ He said, ‘Oh no, the science is going well, it’s Robert. Robert nags me because as you can imagine I don’t come in on time. I come in late and I go early, that’s the way I like it to be. I do some thinking, I think I’m reasonably productive’. And I said, ‘Yes, you are very productive, it doesn’t depend on the hours you put in’. He said, ‘Well I come in at about nine twenty, nine thirty each morning and Robert sees me each day and he nags me because I’m setting a bad example and I really ought to be one of the role models for the place and I ought to be setting a good example, and I don’t know what to do’. I said, ‘Well, the remedy is easy Harry’. He said, ‘How’s that, how’s that?’ I said, ‘Well, how long do you think Robert sits in his office looking out for people coming in late?’ He said, ‘I don’t know’. I said, ‘Well, think about it. Robert is a very hands-on superintendent, he does not sit in his office normally. He’s out going around talking to people nearly all the time, going round the group leaders, going round the other people, he wants to find out what is happening. When he has meetings he wants to finish them as soon as possible. You know what he’s like’. He said, ‘So what?’ I said, ‘So he’s not going to be sitting there at ten o’clock is he?’ And he said, ‘Oh’, he said, ‘What you’re saying is I shouldn’t come in earlier, I should come in later?’ I said, ‘Yes’. He said, ‘How late?’ I said, ‘Well if you came in at ten o’clock I’d guarantee he wouldn’t be there’. So that’s what Harry did and afterwards everything was bright and light, Harry was happy, Sutton was happy, he thought Harry was getting in before he got there, he never cottoned on to that fact. [07:00] But that was one of Sutton’s peculiarities. Another one was his insistence that we weren’t being creative enough, which I suppose there was some justification for. He said none of the group leaders are coming up with enough original ideas, you’re happy to sort of potter along and things are happening too slowly. We need to have a brainstorming. And he said, ‘That’s what we’ll do, we’ll have a brainstorming exercise every Monday afternoon’. The group
leaders said, ‘Well how are you going to do this?’ This was broached at a group leaders’ meeting and we’d say, ‘How are you going to do this?’ And he said, ‘Well that’s easy enough’. He said, ‘We’ll have a room set aside and every Monday afternoon a group of people will meet there under the chairmanship of somebody I’ll nominate and you each have to nominate one person to come on to it’. And we said, ‘Okay, that’s reasonable, okay, that sounds okay’. So he said, ‘Well’ he said, ‘How are you going to nominate these people?’ And we said, ‘Oh, nominate good people’. He said, ‘No, no, that’s not what I want’. He said, ‘The people you would nominate would be the people that you think are good, they’ll be in your own image and logically that’s what I’m complaining about. I don’t want people in your image because you are not producing the goods. I want the people you’re suppressing, the people you think are your worst people because they’re just the people who are going to come up with the ideas which you’re not able to recognise’. So we said, ‘So you want us to nominate our worst people to come and sit in a brainstorming session for one afternoon a week?’ He said, ‘Yes, that’s exactly what I want’. We all said immediately, ‘Well that’s an excellent idea, seeing that we could get rid of our worst people for one afternoon a week instead of having to wrestle with finding them things to do’. And Sutton said, ‘And I’ll nominate a person’ and he named a very nice, fairly pedestrian Principle Scientific Officer who everyone liked who could look after them, so for one year Sutton’s barnstorming group met and surprise, surprise, at the end of one year they disbanded because they hadn’t come up with a single idea. But Sutton was quite happy, he’d tried. Anyway, that was the way in which Sutton operated and you couldn’t predict how he would operate. But I was still a bit surprised when he approached me one day in 1963, I suppose it was, or maybe early ’64, and said that he was taking my group away, just like that. I said, ‘Why?’ He said, ‘Well’ he said, ‘It’s become clear to me that you and I cannot work together in the same establishment and I have no intention of leaving, so would you kindly find somewhere else and your group will be working on a different topic’. Well, I wasn’t very happy but in the end it was his privilege so I had to tell my group they now had a new group leader who was somebody who knew nothing about semiconductors, he came from the neutron tube area, he had lower intelligence than any of them, or any of the scientists there. They were going to have a problem but there wasn’t anything I could do about it, that’s what Sutton wanted, and they would be on a fairly pedestrian task in making markers for films on an aircraft, and I had to look elsewhere. I have to say that I wasn’t the only person because he’d had similar conversations with all of the individual merits in the place in solid state physics and the whole of the solid state physics area was essentially going to be disbanded and people were sent here, there and everywhere, they all did fairly well. A number went up to Manchester, two of them got chairs and heads of
department later on. Oliver Simpson, who was Deputy Director of the whole system, he went into, first to NPL where he ran the basic physics division and later went to the Home Office and became Chief Scientist. Others went to industry and only one of the staff above Senior Scientific Officer level stayed in Baldock and that was John Allen, but he left later on and went up to St Andrews. So the whole area was in the hands of younger Scientific Officers. Of course, much, much later on in the story it happened that I took on responsibility for the Establishment and had the unenviable job of closing the gates finally. I think Sutton probably had died by then. He may not have done, he lived till he was in his mid nineties, and became the oldest person to ever have a helicopter flying licence, which was when he was ninety-two. But I suspect he either would have been really upset or would have turned in his grave if he knew that I had closed his Establishment which he had started. But, I had to look elsewhere. I tried NPL and they were equivocal, they wanted me to come but they felt that politically it would have looked too bad if they’d taken on Oliver Simpson, which they were doing, and took on me as well, it would look like a snub in the, a snubbed nose at the Admiralty so they would rather not. So I checked with Malvern and they were in a very different position, that their leading semiconductor light, Alan Gibson, who’d worked on silicon, had told them he was leaving and going to academia. In fact he went to Essex and had a very good career later on there, becoming an FRS and various other things, and that was great. So they were happy at my coming and they didn’t want me to work on silicon, which is what they had concentrated on, they would rather have a diversion and going into the gallium arsenide which they could see was going to be one of the materials of the future, which of course Sutton couldn’t see, because he was much more concerned with short term devices for defence. And so I packed my bags and with my wife’s consent and happiness, which was something that was really quite a gift from her because she now had settled into a good job at Hitchin Girls’ Grammar School after some years of doing supply teaching, but I have to say that our two daughters were not that thrilled with moving from their comfortable schools in Hitchin to realms that they did not fully understand in the misty, wet areas of Baldock, but that of course is another story.

[end of Track 13]
I believe we just left when I was being thrown out of SERL and had been accepted into Malvern.

What sort of welcome actually greeted you at Malvern?

It was excellent. That was the surprising thing, and I don’t just mean in comparison, sort of being thrown out from one establishment, because I knew it was one person who was doing this. But looking back on it in the last few days as to what the situation was in the country, as far as CVD was concerned, and we have dealt with CVD which placed all the contracts, they must have been appalled because it wasn’t just me leaving there, as I’ve said, it was every senior person concerned with semiconductors who had left to go to different places. Some of them were still in the system, but they were not in the same kind of jobs. So they had effectively lost many of the monitors of this part of their programme and they couldn’t look to SERL. SERL was thought of as the CVD establishment, it was an inter-service establishment and for example, when they wanted people to go to Washington to stay there for two years to keep in touch with the American programme, they would almost automatically come from CVD, from the younger people. So they had this close relationship and suddenly, almost at a stroke, Sutton had abandoned all of these people going all the way up. Ian Ross, the leader, he was sent to Harlow where there was a production lab for the klystron tubes, the vacuum tubes. It wasn’t the powerful radar side that was affected, it was the semiconductor side, the solid state side, which was, as they could see, a large part of their future because all of this was developing in the States and throughout the world and they knew they would be relying on Malvern for a lot of the knowledgeable monitoring. And suddenly they discovered that one of the group leaders was off to Harlow to look after valve production. Another one was going to NPL and was looking after basic physics. I was being channelled away. All of their people were going in different directions and they must have wondered what is going on, because most of the team that was active was now going to be working on this film marker for TSR2, which was hardly very forward looking and once it was gone, what then. Sutton of course didn’t think about that, that wasn’t his concern, that was somebody else’s concern and he had had enough of this semiconductor stuff. But it did mean, also when you actually think about what was going on in Malvern, Malvern had done some of the work on silicon. We had not worked on silicon, but of course the prime mover in silicon, a very, very good scientist, Alan Gibson, had decided that he wanted to go to academia and he’d left for the University of Essex. That didn’t mean to say there weren’t other people left behind, but they
didn’t have a natural focus or a topic which they could centre on. So I now realised that in fact people were quite happy that I was going to Malvern rather than disappearing as I could have done to academia or something like that, because it meant I was their senior person and the system was pretty rank conscious. I had by now been promoted, I had this individual merit promotion as a Senior Principal Scientific Officer, so I carried some status and of course as a result I did carry some responsibility. So CVD was quite happy with all of my contracts being transferred to Malvern, which wasn’t that obvious, because the contract was actually placed with an establishment and logically it should have stayed in Malvern [interviewee correction: Baldock], but there was no way it could have stayed in Malvern [interviewee correction: Baldock] because there was no-one there who could have carried it on. There were three Scientific Officers relatively recently recruited in my area and there was one chemist of some seniority, but there was nobody really who could have done the job. So I think CVD was quite pleased that I was finishing up in Malvern. Malvern of course, the main problem I’d had with Malvern, as I’ve gone into in some length, was Robin Smith. [05:30] And he had departed for Sheffield actually quite a long time earlier, in 1961, he’d taken the job as Professor of Physics and later on he did very well, he went to MIT and he had a good career after that outside the Civil Service. Frank Jones was now at Farnborough as Deputy Director and later on he went to Mullard’s and became Managing Director, so that was all good. So there was clearly a period when I sort of had to settle in and they didn’t quite know how to manage this, they didn’t know me that well, but they knew me reasonably well. My interactions with the infrared missile thing had been fairly good, and also the work on indium antimonide which we had shared, that had been very co-operative. So I knew many of the people there, so that was okay. But it still meant I was a fairly senior person just coming in to the organisation. I didn’t even have an office at first, which embarrassed them. I shared an office with one of the engineers, very friendly man called Mercer. But that only took them a week or so before they organised themselves to actually realise that I did need an office, I needed a secretary. And that was all handled and then they even gave me an Experimental Officer to work with me. I knew what I wanted to do, that was quite straightforward. There were two things I could work on. One of them was the laser, remember the laser had been invented in ’62 and it was now ’64, so we had well developed this, the companies were interested, the system was looking for applications of it, and applications of the light emitting diode as well, which was a simpler version. And in addition we had now the transferred electron device where Gunn in the States had made an embodiment to indicate that the theory was sound, though he didn’t agree with it, we didn’t take any notice, we knew one, it worked and how it worked and what we had to do to make it work. And it was fairly obvious that
the consortium was going to concentrate on the two things with shared responsibilities and there was again pretty good agreement on what each was going to be doing. And this worked extremely well because I think it was – and I’ll look at this now and see that we made the first actual microwave oscillator, it really was a microwave oscillator in semiconductors, early in 1965.

[09:10]

*What’s a microwave oscillator?*

It’s a source, if you have any kind of radar set, you’re detecting an object at some distance and you detect it by sending out radiation to that object and getting it reflected back to you. So you detect the reflected beam, but you have to have a source. Now in the original radars this source was a vacuum tube and the advantage the UK had during the war, or at least during the early stages of the war, was that Harry Boot together with two others at Birmingham University had invented the magnetron. Now the point about this is that although all electromagnetic radiation will be reflected in this way if you do it, if you send out a beam and get it back, I mean this applies to radio waves, but the actual picture that you get back, the reflection picture that you can see depends on the resolution that you have, your ability to pick up objects of a certain size and that is closely related to the wavelength that you’re sending out. So if you are sending out radiation that has a wavelength of a thousand metres, which is a radio wave, you can get reflections back from objects that are a thousand metres in size, but the reflections you get back from an object one to five metres in size are all overlapping, you won’t be able to pick them up, you can’t get a picture, you might be able to see there is some change in the reflection pattern, but you’ll get no essential picture. So if you imagine you’ve got a two-dimensional screen in front of you which you lay out and you’re sending out your signal from the centre of one side, you can imagine that as a series of circles, well, semi-circles that are concentric going out, and then they come back just as you get waves reflected on the surface of a lake from objects and you know that you will get them all overlapping if they come back from the sides. Now you can see the actual size of those waves because that frequency that you’re sending out as a sound wave is equivalent to that kind of wavelength that’s between the crests. So if you have a radar system that you want to pick up a plane, you’ve got to generate in your source of the microwaves – and remember they’re called *microwaves* – a wavelength that is comparable with the dimensions of a plane. And we didn’t have anything like that. Well, we might have had some things that could work at perhaps thirty centimetres, but the key really was trying to get something which would
operate at three centimetres and that wasn’t known at all, but the – it was known that we needed it, but it wasn’t known how to do it. And what Boot and the other two at Birmingham University did was they invented this magnetron, which worked at three centimetres, and that meant we had an immediate advantage throughout the early parts of the war in our radar sets. We obviously passed this to the Americans who started producing them in quantity, and we were producing them in quantity. But this was the system that everybody relied on and when they wanted more powerful radar sets with long wavelengths – sorry, with longer ranges – then they just put more power in, but it was a vacuum tube device. And you couldn’t make small radar sets. In fact nobody thought they needed small radar sets because they knew that they couldn’t have them, because the magnetron itself was quite big, it was about, shall we say, a foot long and about six inches wide in both ways, but it also needed a very high voltage to make it work and a magnetic field. And this meant that there wasn’t such a thing as a really portable radar set. Now, suddenly we produced a device that actually had a short wavelength. It worked in what we called X-band, which was three centimetres. And it worked off six volts. So, what is more, it was a tiny little crystal so the whole thing was portable, the main thing you had in building up the size was the cavity that you put it in, because the frequency, the wavelength that you generated depended on the environment of the device, not on the device itself. It was slightly dependent on that, so you could immediately make a radar set that you could hold in your hand.

*How much smaller and how much less power is that than a typical radar set of the time?*

[15:25]

It was probably a hundred times down on what you would get, maybe more than that, a thousand times down. But you could use the power much more effectively. In fact we showed at one stage that you could send a message using one of our small radar sets from - we put it on the coast - from England to Scotland and back again. We got a message that way. And that was in fact because the transmission was going in ducts in the atmosphere that channelled it, but you can do an awful lot with ten milliwatts, which is what you could get. But the thing that we could do and was important for all radar sets was there was one component that you had to have in a radar set which was called the local oscillator and you used this to actually mix with the wavelengths coming out from your vacuum tube source to transform the frequency to one which was consonant with your circuits that you were using at much lower frequency. You see, if you have a frequency going out, and let’s talk in frequencies because it’s easier, though the frequency is just related to the wavelength, here we’ve got something that is going at ten thousand million cycles
per second. Ten gigahertz. A gigahertz is a thousand million and ten gigahertz, which is ten to the power ten, and you want to transform that down to a frequency that your integrated circuit can easily cope with, or any circuit which will be in megahertz. Now if you actually transform that, if you actually direct that at a component that is already itself vibrating at the same frequency, less one megahertz, the two signals will mix together and you will get out a frequency with lots of other frequencies of one megahertz and then you can play with that. So we could immediately put a very compact local oscillator into all radar sets, effectively, and that meant a great simplification in the radar set. So that was the first thing that people could see doing. But then there was a whole panoply of other things you could do, which again are based on a mixing of that kind, but a mixing of a different nature, and that is called a Doppler radar. Now you may have heard of the Doppler effect, which is actually usually applied to sound frequencies, which is the reason why when a police car approaches you, or an ambulance - let’s be commercial - and as it passes you the sound of the siren changes, it drops and that’s because the radiation as it’s coming at you has its own frequency that is added to the speed that the car is approaching you and as it goes past you, you then get the natural frequency of the siren less the speed of the car. And that is called the Doppler effect. Now if you actually direct a microwave beam at a moving source, you again change the frequency that’s reflected, so you can detect that moving object by the new frequency that’s coming back and of course if you mix that frequency with the frequency that you sent out, you will get back a frequency that is much, much lower and is actually proportional to the speed of the object. So this gives you a very simple kind of radar and it’s a radar that only detects moving objects, so you don’t get any signal coming back from other things that are stationary. You pick up only moving objects, so you can imagine, there’s a whole range of radars that can do that and the one that is very common of course is the one the police use for detecting you when you’re speeding. And that is a very simple radar, one that we made straightaway and we showed you could hold it in your hand and of course immediately the police were interested. It detects moving objects, so it detects intruders, burglars, it’s an intruder alarm. And of course Ministry of Defence were interested in that because you can immediately think of mounting them on fences and they’re much simpler than the beams of light which are all affected by other things. It’s actually quite difficult to get round a Doppler radar. [21:40] We had a demonstration in our laboratory where I put, I suppose it was a five pound note in a safe, and we had children coming in and we said there it is – they could see the five pound note – and we said if you can get there without the alarm going off you can have it. And of course there were queues of these ten, eleven year olds were sure they could do it. And there was one almost did it, I will say, he almost did it. You could hardly see him moving. In fact, if you have a very sensitive one
you can actually detect someone’s heartbeat in this way just with the movements of their skin, yeah. And indeed, there are some applications there in safety in darkrooms and things where if somebody stops moving, is lying on the floor, the main signal goes but you can still detect that they are alive.

_Why are you demonstrating…_

Oh, we had open days for the population of Malvern, because they always had this big establishment of great mystery and we were recruiting people obviously, a lot of the people worked there, but we thought it very good that their families should now and then come in, so we would have an open day. I don’t think it was every year, but it certainly was fairly often, there’d be an open day and we’d put on exhibits so they could see things. Most establishments used to have something like that. It’s all, it’s was all part of the big society, you could say.

_Seems a little strange to have a secret defence research establishment holding open days though. What would happen?_

We had a tremendous number of visitors coming to Malvern, not everything was secret. I have a long publication list here of my work and so did everyone else. There were different bits that had more secret, remember, I should say that there were two departments in Malvern. One was the physics and electronics department divided into two halves, physics and electronics, and the other one was military and civil systems. The military and civil systems was much more secure than ours was, as you got nearer to the edge, so the security increased. Some of what we did in physics was not broadcast and certainly some that we passed over to electronics wasn’t broadcast. But there was a large amount in which we collaborated with companies outside and helped businesses to actually get electronics into their sensors and things, so a lot of it was open. And certainly the open days were open to children and this one, I’ll say, this kid, you could hardly see him moving as he approached my five pound note and I was getting quite nervous. But then he got excited at the last minute and you could see him thinking I’ve done it, and he put his hand out quickly to grab the note and of course the sudden movement set off the alarm. I think I gave him one pound. But… and this was very useful, you could use it. [25:25] An interesting anecdote. I was having dinner, we had just had pictures coming out of, well it wasn’t me, it was an attractive young girl obviously holding this gun, radar gun and pointing it. They had radar guns but they were much more complicated because they needed a high voltage to work them, this one worked
off batteries. So this had started featuring in the papers and people were getting some good publicity and our press office was busy doing this. I was having dinner in Malvern with the classics master from the boys’ college and his wife who we knew very well when the phone rang and Ralph went over and came back and said, ‘It’s The News of the World wants to talk to you’. You know what The News of the World used to be like. And I had obviously left my phone number with the babysitter, which is why they’d got on to me at home, the babysitter had told them the number I was at. So… and what it was, was they wanted to talk to me about the radar and particularly the effect on cars and the police and things. And I said, don’t make us out to be ogres, we’re just doing our job for the Ministry of Defence and developing these things and this is one of the by-products. And they looked at me peculiarly when I got back and I nodded to Betty and said, ‘Oh you know what it is’ and she nodded, but they wanted to know what it was, why I was in The News of the World and all that. Anyway, the front page of The News of the World, would you believe, did what I suppose my schoolmasters had often said, I was a bad influence and in the end I would finish up on the front page of The News of the World. And so I did. Just above a picture of a lady in a nightgown on ‘Why I left the champ for the milkman’. Fortunately this was nothing to do with me, this was a separate thing and it was on our radar, but they said, ‘Don’t make us out to be ogres’. You’ve got to be careful what you say to the press. But it did get a lot of publicity and obviously there were a lot of applications and of course we had a lot of pressure on us to improve the performance of the devices. They were being taken up and we had to make them work better. And that fitted extremely well into the general Malvern philosophy. The difference between physics in Malvern and physics at Baldock, as I’ve said, was we had a couple of theoreticians in Baldock who were very helpful, but in Malvern there was a theoretical physics section, there was a very big maths group which included a pretty advanced computer, which they were improving all the time, [28:45] and they were beginning to work out how you could calculate what went on in the middle of semiconductors. And this was called hot electron effects. On the energy diagram that I’ve described earlier you can think about the electrons in this cup in the conduction state and rising up in the cup and you can represent that as an effective temperature, because temperature is equivalent to energy and electrons were getting more energy so you could express this either in energy terms or in temperature terms. And as the temperature went up you called them hot electrons. And a new field was now developing as a result, obviously of government funding going in all round the world, into hot electron phenomena. And I was beginning to work in my own group because I had by now developed a group and the theoretical physicists were very interested. There were two in particular: Paul Butcher who later went on to a chair in Warwick University, and Bill Fawcett who later became Head of Physics
and Deputy Director, I think, at Malvern. But he stayed as Head of Theoretical Physics for some
time, but at this time he was a scientist and working in the normal way. And they joined in with
myself, and one of our people called David Rees, in these calculations and gradually this spread
throughout the group so a lot of us were working on the theory of hot electrons in semiconductors
and what happened as you applied a higher electric field. And we were helped naturally by
having the computer where we could do calculations which were called Monte Carlo calculations,
because essentially you were seeing how the individual electrons moved and they would clearly
.depart from the average, but you could see how collectively they moved in the semiconductor.
So we became, the establishment became noted as a centre of this work, and that spread and
began to spread much more to academia where people were interested, largely because a lot of
theory could be done without having the need for taming the semiconductors. You could
essentially work with a perfect gallium arsenide because you hadn’t got to make it, you knew
roughly what the band structure was, so you could work with it. And a lot of groups in the States,
in Italy as well, and of course our own group worked, and it began to also spread in the UK, and
it continues to this day as a real study of what goes on in semiconductors when you apply electric
fields enough to disturb the equilibrium. This is the difference.

[32:15]

Where did you get the software from to do these calculations?

Oh, you wrote your own. You wrote your own programs, mostly on tapes. I think there were
punched tapes that put the input in. The software was done basically inside the computer and in
the maths group. You, I mean you knew the form of the program you had to write and there
wasn’t such a thing as software programs – now of course there are, but then, this was really right
at the beginning. You mentioned… I mean computers, well a lot of the computers still used
vacuum tubes. Ours had begun to start using transistors. A lot of them were still using
germanium transistors and they moved gradually over to silicon as they became available. But
the computer itself was changing in its form and there was a lot of research going on in how to
use a… you talk about it as being software, I think of it as being programming. And they were
doing a lot on programs, and on program languages, the language was changing. A language had
been developed at Malvern called ALGOL and that was not used generally, people used different
languages on their own computers.

Did you get any training in how to program?
Someone took me aside and showed me how to write the programs and get them right, yes, I think it was all of twenty minutes or something, yes. I didn’t need it anyway, I could write the program. And they were pretty happy with us because we wrote programs for working out what was going to happen in a semiconductor and we would present it to them and then they’d run the computer all night on the program. So the computer was being used, they were always very concerned that the computer wasn’t being used as it ought to be, I mean it was a magnificent machine, or a series of machines. So we were quite popular. And we were also coming out with results on what was happening inside the semiconductor, which actually was quite complicated. The frequency that came out from the semiconductor was dependent very much on the interaction between what was going on in the crystal and what was going on in its environment. So that was good because it meant that you could define to some extent what was happening by the mechanical way in which you designed the cavity, the, the cube in which you immersed the thing by getting reflections from the walls. The semiconductor is held in a copper rectangular tube, if you can imagine a rectangular tube that’s got reflecting surfaces at the end, and you can adjust the difference, the difference in distance between those ends, then you can alter the frequency that you’re getting out. So you can ensure that it’s coming out at the frequency that you want it, which is more or less independent of the individual device that you put in. But you still want to know what is going on within that crystal because the efficiency with which they converted electric power into microwaves was not high and the moment you make a device the users of the device immediately want to improve it. So there began a new science, effectively, in instabilities in semiconductors and how they developed. And a lot depended on what happened at the ends. The semiconductor is friendly to the instabilities but it wants to control them in some way. Our picture of the way in which the semiconductor would respond to being forced into the negative resistance regime was that the whole semiconductor between the two contacts, the anode and the cathode, would go up and down with the electric field, would go up and down and that frequency would be the one that came out. But in fact that isn’t what happened, that what happened was that you had these domains which would be created at the cathode and go through to the anode and roughly the frequency would be determined by the transit time that the electron went through. Now that automatically gave you a problem in trying to increase the frequency. A lot of the radar sets were beginning to operate at higher frequencies than those were used during the war. The first one we made was working at a frequency of ten gigahertz, 10,000 megahertz, but people wanted that to go up to higher frequency because, as you go to a higher frequency the wavelength is shorter, your resolution increases, so you can pick out
more detail. So there was a move in radar sets generally at this time to go up from what was called X-band, which was ten gigahertz, to Q-band, which was thirty-odd gigahertz. And our devices would not generally do that, but we knew if we could get them to not form into domains, if we could somehow stop the domains from forming, then the frequency would automatically go up. And you can describe this domain that is created at the cathode as being an accumulation of electrons, and that is a space charge, it’s a charge of negative, a negative charge collected at the anode – at the cathode – in that space and a new mode people wanted to work on was called a limited space charge accumulation. And you wanted to change the conditions at the cathode so that that would happen. And various people worked on different things and then it was discovered that if you made the thing too short, instead of getting a high frequency and somehow it became more stable, so there were all kinds of complications coming in from what was essentially a pretty simple device. And then people wanted to complicate the device anyway and make it better, whereas previously we had a metal contact at the cathode, fairly soon we discovered that we could do better by having a doping of the semiconductor of the cathode so that it was more uniform. And that gave you better performance.  

Now, I have actually omitted one very interesting part of this – I omitted several bits actually – but this bit is quite critical because of course I have said that we made the first one, and indeed we did at Malvern. In fact it exploited something that had come directly out from the consortium that I had started at Baldock which now had moved with me and incidentally now had changed its name. It was no longer called Hilsum’s Consortium, it was the CVD Consortium, it was now recognised as working so CVD could take the credit for it. I didn’t worry about it, it was just called the gallium arsenide consortium as far as I was concerned. But one of the things we had done is we shared the responsibility for trying to make pure gallium arsenide between Baldock and Plessey at Caswell and we had each chosen, we knew we had to do this from the gas phase, we had to use a gas, a vapour to deposit on the surface. And we had chosen one way, the Plessey chemists had decided to work on gallium chloride plus arsenic. In fact other people in the States at Princeton were also working on it, they had decided to work with arsine, and we got there first, or at least Plessey got there first. But they were able to put down for the first time pure layers of gallium arsenide and whereas in the solid you could never get the electron concentration, the impurity concentration much less than $10^{17}$ atoms per cubic centimetre, and if you wanted to get a higher resistance material you had to balance the two types of impurity, the p-type impurity and the n-type impurity, we could never get that and when you add more impurities you may get less electrons available for conduction but they won’t move as well through the material because you’ve added more foreign impurities. So those will inhibit the way in which the electrons move
and control the details of anything you’re trying to do in the semiconductor. But now – and that was common all round the world. It probably was the result of silicon in the material, probably. There may have been other things but silicon was probably dominant in doing this. And now for the first time John Knight and Derek Effer at Plessey had deposited layers where the impurity concentration was nearer $10^{16}$, that’s ten times better. And immediately we could make much better devices. Now of course in principle this was supposed to be part of our collective effort to make the red hot transistor and we should have been starting to work on transistors, but although we did have a contract with Plessey to actually make transistors in this way, we ourselves were more interested in making transferred electron devices. I don’t call them Gunn diodes, though most of the world does, because I don’t believe he deserves it. So we called them transferred electron devices, which is the way in which they work, you’re transferring electrons from one energy state to another. So, we actually made them. But of course, this information was now shared with the consortium and within a few months Mullard put on the market a local oscillator. I said what that was, that was a transferred electron device that worked off six volts, it was a local oscillator for any kind of radar set, but would give you a portable Doppler radar for intruder alarms or anything like that. And this was based on the material grown in the way we had perfected at SERL and passed to them on a contact technology developed at STL at Harlow with the way they put the cathode on, which was a tin dot put on with stearic acid, on to an epitaxial layer put down by Plessey, and a structure which I think had come from Marconi. And this was being produced and sold by Mullard, which I thought was a good example of collaboration. And they rang me to tell me it was going on the market in two weeks’ time and I said, ‘How much are you going to charge for it?’ They said, ‘Fifty pounds’. I said, ‘What are you talking about? Fifty pounds?’ I said, ‘It costs you less than about two or three pounds to make’. He said, ‘Well that’s got nothing to do with it’. I said, ‘Why not?’ and they said, ‘A klystron costs you fifty pounds and you have to have a power supply to go with it. This is fifty pounds and all you need is a battery to work it, so why should we charge less?’ So I muttered and muttered. And then the next month Plessey put the same oscillator on the market, exactly the same technology, again coming from the consortium, also fifty pounds. And then STL put one on the market the next month. So all three companies were producing microwave oscillators within a few months, which was pretty good we thought, and was a good example of collaboration. They started selling them pretty widely, people were finding them very useful. So that had come out. [47:00] Of course, my own fortunes were beginning to blossom now. I was beginning to be thought of as the, I suppose the leader of III-V compound work certainly in the UK, possibly in Europe and certainly a leading person viewed in the States. They knew what our groups were capable of and
they knew the way we were working together, which made us very effective. And I gave the,
there was this conference – I think I’ve mentioned it before – every two years the international
conference on the physics of semiconductors, and in 1964 I gave the invited talk on III-V
compounds, band structure, effective charge and scattering mechanisms in III-V compounds. So
that was all working very well and now the group collectively was working together, this
combination of the solid state physics division and the theoretical physics people was proving
very effective and there’s a whole list of publications that came out from us in ’64, ’65, ’66. Not
just me, I hasten to say, I mean the other people were perfectly capable of doing their own
academic work and I began to think of more complications in this series of energy levels that you
have in those compounds, which is called the band structure, the electron band structure. Well,
it’s actually the energy bands because it applies also to the holes as well, and how you could play
around with them. We had known that you could actually mix gallium arsenide and gallium
phosphide together to get a larger forbidden gap, which is what you wanted. We could make
gallium arsenide LEDs, but they only emitted radiation in infrared, what we wanted was a bigger
energy gap and then they would function in the visible. The way in which you did that, you
alloyed it with gallium phosphide. Now gallium phosphide did not have the same detailed band
structure as gallium arsenide. It had the same band structure as silicon and germanium which
almost stops you from getting light out. But if you alloy the two together at a place near the
middle, at fifty per cent or so, you just about get light coming out in the red because you have
increased the forbidden gap between the two states, the electron and hole state, you’ve increased
that enough so that it now corresponds to a visible radiation and you haven’t yet quite moved into
the silicon germanium-like structure which would stop it. But it’s a very close thing. And now I
became interested in what you could do with that top level. And at the 1968 conference which
was being held in Moscow I, working with a colleague, I’d shown that if you actually had,
instead of gallium arsenide phosphide, you had indium gallium phosphide, then you actually
could get an even shorter wavelength. I will say that IBM at the same conference had had the
same idea, but they’d come up with aluminium gallium phosphide instead of indium gallium
phosphide. But, thinking about this how you played around with these more complex levels, I
invented the term band structure engineering, which meant that you could actually make devices
that gave you better properties if you knew what was happening in these, or what you might say
are secondary levels in the material and people began to play around with combinations much
more to exploit this. Not just using three elements – indium, gallium, phosphide – but also using
four ternaries and quaternaries – indium gallium arsenide phosphide – all kinds of complications
started coming up with people coming out with ideas.
What sort of effects does that actually generate?

Oh, the effects aren’t necessarily different but you’re optimising the effects, you’re beginning to learn what controls things like instabilities, light generation, how to get better conductivity sometimes, all kinds of things you can do if you know the details of the physics of the materials. But it is the details and this got me interested actually in understanding what happened in indium phosphide itself and to think of instabilities in indium phosphide. Now this of course had happened throughout the world, once people got used to the idea that you could have this effect of electron transfer in gallium arsenide, people started looking at the whole gamut of materials and you were able to look at them in a much more sophisticated way because you didn’t have to get them that pure and get them working continuously in a CW, a continuous wave action, you could get them working in short pulses and do a lot of physics on that to try and understand. And people showed that in most of the smaller gap III-V compounds, going down, that you could get indium antimonide and indium arsenide and some of the other materials as well, II-VI materials. I mean a lot of materials were shown to have instabilities, usually the higher gap materials all needed higher electric fields, but there was a whole science developing on this. And part of this was I began to look at indium phosphide, together with a colleague called David Rees. [54:40]

And I have said that there are two levels that the electrons can move in, but that’s a simplification. There are actually three.

So it’s fast electrons, slow electrons, heavy electrons, light electrons?

And other slow electrons. There’s fast electrons, slow electrons one and slow electrons two. Depending on the crystal direction, if you think of a three-dimensional material and you can think of going off in different crystal directions, that the, at the centre before you go in either direction, you can think of that being the fast electron state, and now if you go off at right angles to that in one direction in the crystal it’s a cubic crystal, if you go off in one direction you get one set of levels, but if you go off in the third direction – in other words think of this as a left, right thing – you get another level. And you then have to speculate what is the difference between those two levels. And one is called, well the centre one is labelled with an X and then the next one, which we thought was the lowest, was a K and the third one is called an L and we believed that we were transferring from the X to the K. And then I thought well maybe in indium phosphide it’s the L is lower and I began to wonder where the L was and people had given calculations and I thought
that maybe the L is very close to the X and that means that if we actually put more temperature on the electrons they’ll be shared between the X and the L so we can transfer more electrons that way, which will increase our efficiency. So it could be that you’re actually getting in indium phosphide a three level effect and I put out a paper with my colleague, David Rees, who is a genius, still is a genius, the idea that there was a three level. That was in 1970. I’ve skipped some things but this is okay because it takes us on. I’d mentioned indium gallium phosphide, which was ’68, so I’m not that far off. I’ll come back to some other things later on. But anyway, so David did some calculations and I did some and we thought yeah, this seems to work, we seem to get a higher efficiency, and we published it. And immediately all hell seemed to be, get loose and in fact this is the one thing that I published that got the citation record. There was a thing called citations or something, I forget, citation. People were beginning to get interested, now it dominates, in how many people quote your work and if you go into Google Scholar it tells you how many people have cited your work. For medical things it’s tens of thousands. We didn’t know, but they got in touch with me, these – Citation Abstracts I think it was called – they said you’ll be pleased to know that your paper, ‘Three level oscillations in indium phosphide’, has been cited more often than any other paper in semiconductors this month, have you anything to say about this? So I talked to David about it and he said, I don’t know. I talked to other people and I said, what do you think of this? And I mean now we’d started working on indium phosphide which was much easier to work on a second material because we knew how to epitaxially grow it and we knew how to pull it. It was more difficult than gallium arsenide but was possible with what we’d learnt. So we actually were making devices in indium phosphide now. And I sent a thing to Citation… I said naturally David and I are very flattered by people quoting our work, however, we are quite conscious that if you analyse most of these papers they are actually saying that we are wrong, that the theory is incorrect. However, when I talked to the people in the group as to whether this was right or wrong – this came some years afterwards – whether this is right or wrong, they say they don’t care, they say they know indium phosphide works better than gallium arsenide and that’s all there is to it. Which was interesting. And in fact, I’m going to jump twenty or so years. The two materials are used now for terahertz radiation, which is a hundred gigahertz, and you will find there’s a lot of current interest in terahertz. And the standard materials that are used are indium phosphide and gallium arsenide for this. It does work and it’s working because of electron transfer, basically, which people just take for granted, but that is [1:00:50] how semiconductors work if you know what you’re doing with them.
I’m interested in the phrase you’ve used, doing some work on indium phosphide, starting some work. What is the work you’re actually doing on it on a sort of practical daily basis? What activities are actually tied up in this?

Well, it’s, it’s actually analysing the literature that exists on the properties of materials and developing in your mind a pattern, a pattern for how the things change. Now, there’s an awful lot that goes on in a semiconductor, or the interactions between the electrons and the holes and the lattice. I have said that one of the things that restricts the way in which these carriers move through the binary semiconductors like III-V compounds, II-VI compounds, any of these, as opposed to germanium silicon and I suppose I have to include graphene now and carbon, is that there is a charge transfer that goes on. In the lattice itself you’ve got charges, those elements in the third and fifth groups, the actual atoms, the details of the atom, are different on the two sites. So the carriers moving through can sense that and you express this as an effective charge. It isn’t quite a one, as you might expect, or even a two between a three and a five, because that’s what distinguishes them, is the charge on the atom, is a three or a five to balance the number of electrons you’ve got, but it’s a fraction of one. If you’re dealing with something like indium antimonide it’ll be somewhere between point one and point two, it isn’t very strong, but if you get up to gallium arsenide it starts getting stronger. When you get to indium phosphide it is stronger still and so that’s one of the things you have to think about, which is the power of the vibration of the atoms in stopping the carriers from moving and that will obviously depend on how fast the atoms are vibrating, which depends on their temperature. And that of course can be quite important in a device because if you put power into a device it won’t be operating necessarily at ambient temperature, it’ll be hotter than that. So that’s one thing you have to consider, the scattering mechanism. Then you have to consider the actual band structure and the fact that you can represent these energy levels as a cup means that you can actually represent the electrons in that cup as having an effective mass, not an actual mass. The way they travel in the lattice depends on the field and the scattering mechanism and what is happening in detail in that cup and you represent that as a mass and the mass in gallium arsenide is 0.067, or 7, something like that. In indium phosphide it’s slightly higher. And then you’ve got the mass in the other minimum. That would be the mass in the X minimum, then there’s a mass in the L minimum. I think I have to say that there is probably a school of thought now that says that it was never the X minimum that we were dealing with, it was always the L minimum, that the X minimum is higher. Not that that matters, that’s an academic detail. Everyone agrees there is an upper level. And there’s also, that gives you the width of the cup too, which tells you how many electrons you
can put in that cup. You see, the electrons will share themselves. When you start off with them in this fast state where the mass is low and they’re moving very fast, as you put more energy in, because that cup is narrow they will be moving up in that cup and that’s why they move across. The proportion that moves across depends on how much room there is for them in those other energy levels and the broader the cup, the higher the mass, the more states there are so the higher the probability there is of them moving across. So if you can involve more levels then your departure from Ohm’s law will be greater, so you should be able to make a more efficient device. Similarly you get thoughts arising about lasers and things as to how you get, play in the other levels there if you’re not careful. [1:06:30] So the way in which you operate is you try and get a pattern for the materials and of course now you’re talking about not just gallium arsenide, indium phosphide, aluminium antimonide, you’re thinking about gallium indium phosphide. What is the pattern I am getting in these materials, and that’s where band structure engineering comes in. And you’re dealing with probabilities because it’s more difficult to measure these more sophisticated parameters inside the semiconductor. You can get the straightforward things like the energy gap of the material, is a pretty simple measurement and you can deduce things immediately from it. The scattering mechanisms is more sophisticated. It controls the mobility but the mobility also depends on how pure you make the material. You can get a feel for that by changing the temperature because there are different scattering mechanisms inside the material that control or at least affect the transport of the carriers and you can get a feel for then the pattern from measurements, but you get a feel for it rather than being able to write down exactly what is happening. It’s much easier now, I mean you’ve got more instrumentation, you’ve got more effects, more history. So you’ll be able to say things more accurately. But then it was very much going on what you felt was the way in which things varied throughout the material. So you see the feeling that indium phosphide was a better material came from really studying the family as a whole. Indium phosphide had been neglected previously, there’d only been one group that had done much work on it and they’d given up, because it was more difficult. You’re at a time when almost whatever you did would actually yield results that you could publish and build up your reputation. It didn’t necessarily mean that you were doing something important so you had to neglect things and it wasn’t always obvious which was going to become important. So somebody could work on indium phosphide and meet problems and decide that they could spend their time better on something else, on doing more on gallium arsenide or more on silicon or more on germanium, you could get more papers out, get your boss happier that way than persevering. If you had this feeling, then you persevered.
What does that feeling actually feel like?

You couldn’t be sure, but of course you were operating from a position of strength because you weren’t putting everything into it. You had the gallium arsenide carrying on at the time. I’m sure that at the time I was working on indium phosphide I was also doing quite a lot on gallium arsenide and indium gallium, I mean for instance here I’m talking about spectroscopy of indium gallium phosphide and graphical methods of calculating the efficiency.

[1:11:00]
*Interesting, those two paper titles you read out then, they’re sort of talking a little bit about methods – spectroscopy, graphical methods. I’m still having a little bit of problems just visualising what were you actually doing on a daily basis once you’re actually in work. Could we perhaps talk through what a typical day was like at Malvern?*

Can’t really remember, but I expect I was mostly talking to people, I had a group by now, quite a large group and I’d be talking to them and I’d be doing some calculations of my own, I’d be thinking of the results that I’d got, I’d be talking to the people about their results.

*Who else is in the group?*

Oh, do you mean the names of the people or the number of people?

*Whichever’s…*

The group was probably about ten to fifteen by now, strong. I mean these weren’t, I mean I was an individual merit group so people came and joined the group voluntarily. It was now established, we could make devices, that was the thing. At Baldock they had industrial workers, they were called, we were non-industrial grades, but to make vacuum tubes they had, usually they were young women who would assemble the parts. They had engineers, if you can imagine there were people obviously who knew how to make it and had designed the devices, but now they had to be made and these were pieces of copper and various things that had to be put together. So there’d be, at Baldock in the main shed, which was a huge shed, there were a hell of a lot of lathes and equipment for operating for turning metals and there were engineers who were really engineers, these were industrial people, they weren’t scientists. They would be turning on their
lathes pieces of copper and sometimes gold came into some of these things. And then, when they had finished doing it, there was a line of women who were now actually constructing the final device, and they were called valve assemblers. So there would be fifty or so valve assemblers. And we started using them to make – well them, not them, but equivalent young women - to make the semiconductor devices. I mean the scientists did not make the actual devices, they designed the devices and then told the women what they actually wanted them to make and they would then make it. When I came to Malvern they had nothing like that, because they’d never had the same kind of need. They used to use their laboratory assistants to do it, who were a level in between. The laboratory assistants were people who knew some science. They wouldn’t necessarily and probably hadn’t been to university, but they would, people who had studied science and maybe had left school at eighteen or something. But now, I introduced and recruited young women – I don’t think they were called valve assemblers, I’m not sure what they were called even – but they weren’t laboratory assistants, they weren’t assistant grades. They may still have been called valve assemblers. But they would be making the things and of course by doing this I had built up an infrastructure for making devices and so there was a premium for people to come and work with me if they wanted to do this. So we had this dual structure of people who were making devices and measuring devices and designing devices and we had the theoretical physicists doing the physics of the devices. And then in addition, not to be forgotten, at Malvern there actually was a professional division called the Materials Division, who were actually making materials of various kinds and they now were getting interested. When I came they became very interested in actually working with me on gallium arsenide and beginning to reproduce some of the work that was going on in Plessey. And their expertise was actually in crystal growing. They would be growing the single crystals and they had developed some techniques for dealing with growing these crystals at high pressure. We had done that at Baldock, but it was very difficult to actually grow these single crystals at a pressure of one atmosphere, you had to have all kinds of ways of getting seals to go through without letting the pressure out, it wasn’t easy at all. How are we doing? And one of the things I did which was almost peripheral to me, but was quite important actually to the future of gallium arsenide and for the Materials Division, with a man called Brian Mullin we had come up with an idea for pulling the crystal through a blanket of liquid that if you took a material like boric oxide and you spread this over the surface of your gallium and put it in, it would insulate the material, you could pull the crystal through this. And although you had to have the material at pressure, the arsenic did not escape, the arsenic was kept underneath the blanket. And it was called liquid encapsulation. They developed that, patented it and it became the standard method for pulling materials. There
was some history and somebody else had done it, but Brian and his team perfected this and they
worked with me and of course that was a real forward step because whatever you say about
epitaxial growth and how pure it is, you’ve got to put it down on something and the method we
had at that time for getting the single crystals did not give you very large surfaces. It was a tube
that you did and you were lucky if you had something more than a couple of centimetres across,
and very often it was less than that. But here for the first time you actually could pull quite large
crystals and it meant that gallium arsenide was beginning to get normal in that way.

[1:19:00]

Why do you have to have a single crystal?

Oh, because you don’t get the properties. You have to have a single crystal because otherwise the
properties will be dominated by what happens at the junction that you have between the two
materials. If you’ve got different crystal directions you get a fault in the crystal. Not only is there
a fault there that the electrons can’t easily go through, that will be propagated in your epitaxial
layer. Also you get impurities congregating at the defect in the way the crystal grows. It is, this
doesn’t apply to all the effects. Quite a lot of solar cells now are made from a polycrystalline
material where there are grain boundaries, but people learn how to deal with it and indeed, quite a
lot of the progress on the reduction in cost of solar cells has come from the fact that they now
know how to grow extremely large single crystals of silicon and the whole thing becomes
cheaper then, you get a much higher yield. So this is what you were seeking and for the first time
we had it. At the same time the group at Malvern were able to reproduce what Plessey had done
and were able to make good epitaxial layers. So essentially I had the infrastructure for doing this
and as we were successful so more people wanted to work with us, I mean success breeds success
and then as a result when we started on indium phosphide they were very keen on getting into
indium phosphide, even more keen because it was something where there was nobody else
working on it. I mean we were working on indium phosphide, nobody else was working on
indium phosphide at the time, it was too difficult and they weren’t convinced they would get the
results. They preferred to do more things on gallium arsenide by now, they were following
behind us, so we were able to get a big lead.

Why pursue indium phosphide if it looks like it’s going to be difficult?
It’s better. That’s what I said to the people when we had the citation, I said do you think indium phosphide works on three levels or two, and they said don’t care, works well, better than gallium arsenide. And there you were, once you’d overcome the problems you now could make something and that’s why, I mean, I don’t know what the feeling is now on terahertz radiation, but I know people are working on indium phosphide and they probably feel that it goes to higher frequencies and this is very much the subtlety of the top levels and what happens there, which you have to infer because it’s very difficult to measure these things. So yeah, I mean that all started then and it worked. So that’s what was happening.

_Were there many women scientists?_

Mm?

_Were there many woman scientists? You mentioned the valve assemblers, I was wondering about further up._

I recruited a woman scientist and actually wrote some papers with her. Her name was Jenny Welborn and she was very bright and I was extremely disappointed when after two years she said she was leaving. And I said, ‘Where are you going?’ And she said, ‘I’m going to go into radiotherapy, basically, and work in hospitals’. And I said, ‘Jenny, you know that in a hospital the fact that you’ve got a PhD is not going to count, that essentially you’re not medical, you will be a second class citizen’. And she said, ‘Well maybe, but I really feel that the atmosphere here is too competitive’. And I didn’t understand that quite, but I think it was very competitive but in the nicest way. It wasn’t competitive as I understand it was competitive in some other places with people wanting to steal results from other people and use them, it was very co-operative but it was competitive in making your reputation, in thinking of things to do and then capitalising on them. That it was a pretty free atmosphere. I mean I didn’t always know what people were doing. In fact all I knew is that they kept on stealing my room, that I would sort of be, I would have a laboratory obviously, and people would come and edge into it and before long they would be using my space without any respect for me at all. I mean that wasn’t the way it functioned, it wasn’t hierarchical. And I suppose I wasn’t there all the time. I still had the consortium and that meant there were a number of contracts that I was handling and I was beginning to handle more because as gallium arsenide, we still were working on the transistor, we had a contract, and I had to work on that, had to handle that with people. And also I was getting involved, and this is now
becoming quite interesting because [1:25:00] it now brings me into conferences and things, which was a very interesting development and we’ll deal with that before we go to lunch. A lot of progress in the field of semiconductors and particularly in applications of semiconductors came through discussions that went on in a pretty free way between the physicists and engineers working on them and there was the Device Research Conference in the States which was an occasion when unpublished results were passed around, and I have mentioned that. And you also have to appreciate that most of the progress in semiconductors in the world did not come from academia. The way in which research was funded was very different and a lot of it was defence research in the UK and in the States and also in France, and I’m not sure about Germany, Germany may have been a bit different. But it wasn’t in academia, it was in industry and government establishments, that if I talk about the first lasers, the first lasers that were made, one was made at IBM, one was made at General Electric at Schenectady, one was made at General Electric at Syracuse, one was made at the Lincoln Laboratory in the States which was fully funded, it was part of MIT but it was a separate laboratory funded for radar research by the Department of Defense. That’s four. One was made at Baldock and those are the first five in the world and it hasn’t touched academia, not got anywhere near academia. And everyone took that for granted. I mean if anyone else had come in it would have been Bell Telephone Labs and RCA Princeton, it wouldn’t have been a university. There was – and they weren’t the only places – there was Texas Instruments, there was Raytheon. All of these were the leaders and our gallium arsenide consortium, who was in that? Plessey, STL, Mullard’s, Marconi. No mention of any academia and that was the way research was done then in semiconductors. It was very much a thrust towards the applications, leaving academia behind. Now I’m not saying they weren’t working on these things. Another thing, they didn’t have access to materials, they had to beg for them, for the materials from the people who were making them, which were industry and government establishments throughout the world. I mean Siemens had been doing some work on these things, but they again were industry. Philips were doing work in Holland, that again was industry.

_Do you think there were any advantages to having industry and government labs working on it as opposed to academia?_

[1:28:25]

Sorry, what was…?
Do you think there were any advantages or disadvantages to having industry rather than…

Well there were at the time great advantages, because things were happening quickly. I mean much research then in academia was being done by PhD students. Well, a PhD student is not really a professional, he’s learning how to do things. It isn’t the optimum way of doing research and in fact there are many places that were doing research that didn’t have students, and in Russia and to some extent on the Continent, they had research institutions specially to do research. They might have had some PhD students but that wasn’t the reason why they did it, the actual professionals did the research. Things have changed now, I don’t know what is best, I mean we don’t have it so there’s no point in speculating on it. But I’m making the point that a lot of the unpublished collaborations came through the Device Research Conference [1:29:30] which the Americans had. And in this country and in Germany we began to think that we ought to have our own. It wasn’t that we weren’t able to share, but we felt that not everybody could go to that, and there had been a conference every year on solid state physics in the UK and this, a lot of Europeans came to it. It was a chore, it was always held in Manchester and always held on January the first or second or third, so it interfered with the New Year, and also it was always very cold up there. It was not good. It was run by the Solid State Physics group, I think, and as things happened I became secretary and I had to organise it every year for a few years and I tried to get it moved from Manchester and from January, but without much success. I remember some of the Swiss wanted to come across, they didn’t want it moved because they said it would interfere with their ski-ing. So I grumpingly accepted this, but decided that I could move it to March, I managed to move it to March, not from Manchester at first, but March. And the Germans had started another conference, which they called the European Conference. And they called it the European Conference, the European Semiconductor Device Research Conference, and I knew the people quite well at Munich who were running it, I knew the head of research there, Walter Heywang, his name was, and we got on pretty well. And at our conference Heywang was there and a man from Philips called Leo Tummers, very senior in Philips in Eindhoven, asked for a meeting with us and so we had a meeting with him. We said, ‘What’s on your mind Leo?’ He said, ‘You two have got to get your act together’. ‘What do you mean?’ He said, ‘What are we supposed to do, which conference are we supposed to support? You have the German conference and you have the British conference. Why can’t we have a European conference?’ And the German said, ‘Well, ours is the European conference’. He said, ‘It’s not, not while there’s a British conference’. I said, ‘Well, I can’t stop the British conference’. He said, ‘Well, I’m not sure’ he said, ‘Why don’t we have a really European conference?’ So I
thought, why not. So Walter looked at me and said, ‘Why not?’ So I said, ‘Well, there is one thing. We can’t just have semiconductors because a lot of the research that’s going on in the UK is on the solid state, on things other than semiconductors’. I mean there are many things, ferroelectrics, all kinds of things were going on. And he said, ‘Well that’s easy, all we have to do is add another ‘S’’. I said, ‘Add another ‘S’?’ He said, ‘Yes, ours is called ESDERC, European Semiconductor Device Research Conference. So we add another ‘S’, it becomes European Solid State Device Research Conference’. We said, ‘Yeah, okay’. So we agreed and we said in March, and then Walter said a funny thing. He said, ‘There’s only one thing, one condition that we put on it’. I said, ‘What’s your condition?’ He said, ‘It must be in English. We have to have papers delivered in English’. I said, ‘But it’s partly a German conference and a European conference’. He said, ‘Already we insist our conference is in English because our scientists have to learn English and they won’t learn English unless they realise that their papers have to be delivered in English, and the reason why they have to be in English is not because of England, it’s because of America. That’s where most of the work is going on and we…’ So we agreed that we were going to have a European Solid State Device Research Conference in England and the first one was held - I have to be precise in this because reasons which will become obvious in a minute. [pause] I thought I’d got this piece of paper. The first one was held in 1971 in Munich, the second one was in Lancaster in ’72 – we’re getting on a bit, but it is important – third one was again in Munich, ‘73, and the fourth one was in Nottingham in 1974. And it had now become organised and we had an organising committee. [1:35:30] And by now I had pointed out to them that the French would not like it, and the French did not like it and the leader of the dislike was a man called Maurice Bernard, who I got to know very well later and in fact he’s coming over, he is a friend and he’s coming over to the anniversary of the laser, and he’d done quite a bit on the theory of the laser. He worked for the equivalent of the Post Office in France and he had complained that really if it was European it had to be France as well and it had to be a triumvirate. [telephone ringing] Philips didn’t want it to be held there.

[break in recording]

[1:36:20]
So, the Germans were very reluctant. I said look, there’s no way, I mean you’ve got to do it, there’s no way out of this. So we agreed that the next one was going to be in Grenoble, and at our Nottingham conference the French announced that the next conference would be at Grenoble, which was okay. Except they put out leaflets, I didn’t know they’d put out leaflets. And I think it
was the second morning of the conference, I came in, took my seat, got ready, and chairman went to call the first... but suddenly a German got up in the front row, Heinz Beneking from Aachen, and said, ‘I have something to say before we start’. And the chairman said, ‘All right, come and say it’. So Heinz went up on the stage, he said, ‘This conference has proceeded well as a European conference for three years and everyone was very happy. Now the French want to join in and we welcome them. But, they have given us this leaflet here which has been distributed to everybody. The first thing you will notice is on one side the announcement of the conference with the details is in English, you turn over and everything is in French. The conference has always been in English and here is French. And what is more, at the bottom it says on the English side, the official languages of the conference will be English and French. And on the other side it says the ‘langues officielles seront françaises et anglaises’. This is against the principles on which this conference has been founded and I call on now, now, for the chairman of the organising committee to tell us what is being done to stop this departure from the agreed way in which these conferences are organised’. And everyone, he said, ‘I demand that the chairman tells us now’. And everyone started clapping, and I started clapping too, until, you can guess, I suddenly realised that everybody was looking at me. Because I was the chairman of the organising... yeah, hm, yeah. I had no idea that, Maurice had never mentioned this to me, nor had Joseph Borel who was the other Frenchman I knew well. So, anyway, what could I do? All I did was I went up to the stage and made one of my best speeches saying I was in complete sympathy with what Professor Beneking had done and I thanked him for his intervention, it is very important that we have an agreement on this, and they can be absolutely certain that the organising committee has this completely in hand, there will be discussions going on and they know that what will be resolved will be in the interests of the scientific community of Europe as a whole, and I ask now that you put your faith in us and let us make our decision in time and carry on with the work of the conference. And everyone clapped. And I went back to my seat and everybody says, ‘What are you going to do?’ I said, ‘I haven’t got a clue’. And I hadn’t got a clue, but we had to get together, it was something we had to do, and the French said we have to have, I mean we have to have something like this, and I said, not necessarily. And he said, ‘What do you mean, not necessarily?’ I said, ‘We don’t have to have an official language for the conference’. He said, ‘What do you mean by that?’ I said, ‘Anybody can give a talk in any language they like, but we will not have translations’. Now we’d already had this in Russia where there were translations, I mean official translations and things. I said, ‘We will have no facility for translation, so if somebody wants to give their talk in Hindustani, they can give it, and people don’t want to stay, they will walk out. There will be parallel sessions anyway, so people
can walk out. You can give your talk in any language you like’. And Bernard said, ‘Yeah, that would be all right. Yeah, I could sell that. If there was no language, we could give our talks in French?’ I said, ‘Yeah, if you want to give your talks in French, you give your talks in French’. Heywang wasn’t too sure, Tummers wasn’t thrilled, but then they agreed and then they said, there’s only one thing, Neel who is opening the talk doesn’t speak English, so what do we do?’ I said, ‘That’s easy, you have your translation there for the first, the opening talk, and then it’s taken away, the translation goes away. And it’s announced, there are no translation facilities’. So, at Grenoble, I think there were probably about twenty talks given in French and nobody listened. The French stayed, I mean there may have been audiences of three or four to their talks, the others all went to the parallel session, I didn’t have to do anything. Nobody ever after that ever delivered a talk in anything other than English, which I think was one of my victories. And you don’t get talks now delivered, except sometimes in Russia and things, there are on occasion talks and maybe, there has to be translation in Chinese, in China. But nobody ever thinks about it, French included. And the conference is still running. [1:14:20] A few years afterwards the circuits, the semiconductor circuits conference wanted to be included so it became a joint conference of circuits. It then was run separately but a few years ago it agreed to come in and it’s just one conference. And a few years ago there was the twenty-fifth anniversary and Tummers, it was in Florence I think or… may not have been Florence, it certainly was in Italy, and we were elected fellows of the conference, the three of us. Unfortunately, both Tummers and Heywang are now dead, so I’m just left as the founder.

How important have the conferences been to…

Oh, critical. Absolutely critical to… actually, the invited talks are very good and they actually sort of stimulate discussions and things, but it is a very important feature of work on mostly semiconductors, but then other things have come in now, ferroelectrics and things like that, thermal imaging, all kinds of things. A critical venue, it’s just accepted that this is where papers are given and obviously after that they’re published in the more normal journals.

What’s the importance?

What is…?

Why is it so important?
It’s a different community to the one, you have the academics but you do need a venue where those who are exploiting the progress actually can get together in a way where they can talk without the limitations of commercial confidentiality. We had begun to break those down with the consortium and the consortium philosophy spread and indeed, in some of the European things the European Commission insists that people do talk freely and there are, I mean when you sign up for it you agree that you will not hide secrets from the other people that you’re collaborating with. But even so, there’s an opportunity for drinks in the evening and discussions – and questions you can ask. I won’t say that when somebody is asked a question they always answer it completely, but the chairman can quite often frown on somebody when he says, oh well, I can’t talk to you about that. The chairman can say look, when you come here you really shouldn’t be keeping secrets. If you’re going to give a talk on it, it’s not meant to be an advertisement for your company that you are doing this and aren’t you clever, it’s meant to be a sharing of knowledge. And so that’s why they’re important. Okay?

[end of Track 14]
Were there any other demonstrations of the microwave radar?

Yeah, there was one that is actually very significant because it got us a lot of prestige. You mustn’t think that all of the time we were working on sort of our own interests and things and nobody came to us to give us things to do, and ideas. That’s not true, we were constantly approached by the military, obviously our programme had to be approved and that was pretty good, that was fairly easy, there was no real problem, because they were pretty sympathetic. Except, sometimes we had a little bit of trouble with people trying to push things. I had positions in the Ministry now as well. I was, there were things like the Joint Infrared Committee that was still functioning and I was still responsible for infrared and used to go across to the States quite often to meetings there which were kind of mixture of semiconductors and infrared. And in this country we were asked for advice on certain things that happened. And one that was quite interesting and important was at the time around 1970, ‘71 or ’72, so a little bit later when we were well established and doing things. They approached us with a problem they had in Northern Ireland and I was brought in generally to look at things and they said they had a problem with snipers, that essentially people would fire at the troops that either would be vehicles or individual soldiers and it wasn’t so much the casualties, though there were casualties obviously with snipers, but with essentially the disorganisation it caused because it was very difficult to locate the sniper. That there’d be echoes of things, they would be on rooftops or firing from windows of the flats, the Divis flats in Belfast, or anywhere. And he said we actually, you have no idea where they’re firing from and we can’t really retaliate, we can’t catch them. He said do you have any way of actually locating a sniper? And I thought about this and there were two schools of thought. We were approached at the same time as other establishments were approached. Our infrared group said we can locate them by the muzzle flash, we will have a system which essentially is looking in all directions, mounted on a vehicle or give it to a soldier and it will detect the flash, we can work out the sensitivity that we need but we can use our infrared expertise to do this. The establishment at Sevenoaks, Fort Halsted, the army establishment, said well we think we can use sophisticated software to locate the thing by essentially the acoustics, the sound. And I thought about this and I said I think that really the infrared thing is too susceptible to countermeasures, they can put a suppressor on and suppress the muzzle flash. So once they know you’re doing this, and they’ll surely find out, they will put suppressors on, you’re done, and you’ve wasted all the time in developing the equipment. I said acoustics will be fine in the country but that’s not
where you have the problem, the problem is in the town and you will have echoes from all the buildings and you need pretty sophisticated software to sort out the real sound, direct sound from the echoes. But they said they were going to do this anyway. And I said I think you ought to be able to do it by radar. And they said how can you do it by radar? I said because there’s one thing you can be certain of, the bullet’s going to come pretty near you, so it’s a target that’s at very short range. They said, yes. And I said, and you ought to be able to differentiate because there isn’t much that’s travelling at the speed of a bullet. So you could have a system that is actually programmed to work for very fast objects very near you. And they said, but how are you going to do that? And I said well, I’m pretty certain we can use one of our miniature radar sets. So he went away, it was only the first meeting to decide on which one was going to be preferred and which was going to be backed. So I set up one of our small radars – oh, I said I was going to show you one didn’t I? Yes.

*Shall we do this bit first and then we can…*

[06:15]

All right, okay. So I took one of our small radars and I put it in the corridor and I found a motor and I put a bit of string on the end of the rotating thing and I put a ball bearing in a little cage so it could whirl round. And I put this, so here was the corridor, there was the motor, there was the thing whirling around at right angles. And I set up to do this and started the motor going, went down the other end to look at what was happening with my radar set, by the time I got there I was getting a little pip immediately coming: *peep, peep, peep*, this went around and before I could start rejoicing the bloody ball bearing came off the string. It went straight through a door in a lab, it went through the door. I don’t know whether it went through the… but it could well have gone through the plywood – it may have gone through a window or something – but anyway, when I came rushing up to find out what it… I found an astounded scientist who was muttering that this ball had started bouncing around his lab and what the hell. Well, there was an enquiry and they knew it was an important application so I was allowed to continue with my experiments, but I had now to turn the motor sideways so that if the ball bearing came off again the only person who would be damaged was me. But I had proved my point and went on to prove my point that I could detect something the size of a ball bearing at a hundred yards, under favourable conditions. And it was fairly obvious that I’d be able to detect a bullet. So, the system was happy. How are you going to do this, and we developed a system. It was largely David Rees who was our resident genius, I spoke to him again, he was actually doing very well on semiconductors and the
theory of Monte Carlo and all that kind of thing. And he devised a very simple circuit which essentially measured the position of the bullet three times, three times. It was triggered first of all at a distance by the bullet approaching, because there was only one thing at that speed, and then immediately would measure where the bullet was at three places and then continue, then you got the angle so you actually got the angle. You didn’t get the range, you got the angle. But that’s what they wanted, they wanted to know in which direction they were going to look. But then we realised there was a complication when we came to think about it, that essentially when somebody fires at you whether you’re in a vehicle or you’re a soldier, you do not hang around, you move. So immediately you have lost your position, that although your system will tell you exactly where this bullet came from, you won’t continue in that direction. So you need a system as well that tells you how far you’ve moved. Now, today you would do that probably with accelerometers, but then we didn’t have anything that was like that, it would have been complicated. Until one of the people in the group, Adrian Mears, said, ‘We can do direction finding’. I said, ‘Direction finding?’ He said, ‘Yes. We’ll direction find on a radio station. We can easily do that with antennas to see where a radio station is, we’ll tune on to a radio station and then we will immediately be able to work out the angle that we have moved through’. I said, ‘I’m not certain about this’. And he said, ‘I’ll prove it’. So he went out in his car and drove around Malvern and showed that he could actually identify Droitwich. He tried various stations and realised that the best station was Droitwich, it was the most powerful and could do this. And the system was developed immediately to locate this and we showed that under all conditions you could get the angle that the thing had done. So we set up and made the circuit, did experiments – not at that time with bullets of course – but showed it works. [11:20] What was more, it didn’t look like a radar set, because it was a strip circuit [interviewee correction: strip-line], it didn’t need an antenna because you weren’t doing something at a range, you were doing something within a few feet. It had an antenna, it was about two inches long, it was part of the strip circuit [strip-line]. And indeed, when you… picture somewhere. I’ve lost all my pictures. It was a sort of rectangular box. Ah, there we are. Like that, or that. And you can’t even see it on the car because it’s behind a panel that was fibre optics. You could put it on the side of the tank and nobody would know what it was, so you didn’t run the risk that if you were in a vehicle or a tank that somebody would throw bricks at it and do it in. Nobody knew. It was trialled down in various places. It was a very rush job, there were meetings all the time. It had to be done within six months. And it was conclusive. Meanwhile, the thermal thing had been thrown out. They proved that the countermeasure was… they never developed the software, they did later on. And the radar system actually worked perfectly and indeed it was made by Racal - there’s a thing that
describes it. There’s a piece of paper that tells you all about it. It’s called Claribel. And one of
the people who’d agreed to join me as an engineer earlier, he adopted it and he was responsible
for the project management. It was developed in six months, made by Racal and the first models
were put into Northern Ireland and sniping stopped. And we were really disappointed because
we’d hoped to see some snipers being arrested and taken off in chains, but what actually
happened was that once they realised that the soldiers knew where they were, whether this was
done on vehicles or people, and we did develop one for the individual soldier that was pouches on
their shoulders, they didn’t like the idea that immediately the people would stop and start moving
directly towards them, they could see that they knew where they were. And they did use it on
some stationary places where they were and they could use to fire there and they knew
immediately where they were firing from. Anyway, this exploited obviously not just the
microwave system but also the displays, because by then we were working on displays and we
had some electro-luminescent displays which we then put into the vehicles there. So it all fitted
in with what we were doing. You didn’t have to have a complicated cathode ray tube or anything
like that, the display was a simple flat panel display, it wasn’t liquid crystal, it was zinc sulphide.
We hadn’t mastered liquid crystals by then.

[15:10]

On a job like that, how much direct contact do you actually have with the military?

Oh, we had a lot of contract with the military, particularly when we went down and had them
bloody firing at us with real bullets. There is a place on Salisbury Plain, there’s a village that
they’ve taken over where they trial equipment. But yeah, we didn’t go to Northern Ireland, partly
because they wouldn’t risk us in Northern Ireland, but we had a lot of contact. The people
actually, David Colliver who was the project leader, had more contact than I had. There was an
interesting thing when we came to do the specification of the system, because they said this has to
work twenty-four hours a day, seven days a week, because we never know when we’re going to
be attacked. And we said, well that’s fine, there’s no problem. And then we thought, oh just a
minute, we’d better check Droitwich. So we checked on Droitwich and we discovered that
Droitwich goes off the air at two o’clock in the morning once a month for servicing. So we said
to the army, is this all right and they said no, course it’s not all right. He said, we can’t sort of
stop - and this is why it was being developed. So we did some research and came back and said,
‘Well, we’ve discovered a long wave station which is on all the time’. They said, ‘Oh good, we’ll
use that, where is it?’ And we said, ‘Radio Moscow’. He said, ‘Radio Moscow? ‘We said, ‘Yes’.
They said, ‘We cannot put in a British specification that is going to exploit Radio Moscow’. So they actually built a radio station in Scotland, a long wavelength station, didn’t have to be very powerful of course, but they actually built a radio station to do the direction finding for us. So everyone was happy, we actually were visited by Farrar-Hockley who was the Chief of the General Staff at the time, to come down and congratulate us and thank us for what we’d done. When I saw him and I accepted his congratulations and said, ‘Yes, it’s a good thing we didn’t stop the work when you told us to then’. And he looked at me and said, ‘I’ve not been here before, I never told you to stop the work’. I said, ‘No, no, it wasn’t you, it was the brigadier who came two years ago and said that this was a waste of time, we should stop it, he wasn’t going to support it, and he was speaking in your name’. He turned to the man who was taking notes by his side, said, ‘Find out his name’. And nobody ever thought of stopping the work after that. I mean it was a good thing, I mean it was something. And I think a few years ago when somebody was talking about a new system that was being made, one of the scientists, very senior scientists who knew me, he said, ‘Why don’t you use Claribel?’ They said, ‘Claribel, what’s Claribel?’ And he said, ‘Well, you’d better ask Cyril, he knows all about Claribel’. And I did know all about Claribel, but they wanted to reinvent the wheel. And there’s nothing in the system which is now out of date. It would still work and is much simpler than the systems which are being used, which use lasers and all kinds of complex things. You will find if you look up sniper location, you will get a lot of references coming to different systems, largely developed by the Israelis. But none of them use radar. Later on another, some of the… it was always a thorn in the side of the systems part of Malvern that this system had been developed by the physics group, because we didn’t use them at all. It was quite straightforward, once we had the basic idea there was nothing that was difficult to do, it was all pretty standard technology, though it was very advanced. It was the concept that was advanced rather than the technology, so we could cope with it all. And the systems people never quite liked it, so in the end they actually did build a radar system that did it. It was quite a nice radar system, and it looked like a radar system, it had an antenna, an all-round antenna mounted on the roof of the vehicle, and it did the job, but we said ours is simpler. [20:00] Theirs was probably better, but still. So, that was a sort of a digression.

*I was interested as well, I saw the video of you and the miniature radar set on the BBC website a while ago and you mentioned a demonstration with a train.*

Yeah.
What happened in that case?

Well, we were obviously always interested in publicity for what we were doing and the Ministry of Defence – no, I don’t think it was the Ministry of Defence yet. I doubt if it was Ministry of Defence, I think it was Ministry of Aviation we were working for, we tended to change. We had the Ministry of Aviation and the Ministry of Aviation Supply before it became Ministry of Technology later on and then some years after that we went back to Ministry of Aviation and eventually there was a Ministry of Defence. But at this time I suspect it was Ministry of Aviation. But they were very keen on showing the public that their money was being spent wisely and things were happening and it wasn’t just all stagnant. So when we came up with something like this we always tried to show something at the Physics Exhibition. The Physics Exhibition was annual, was at Alexandra Palace for some time and then it went to the Horticultural Hall, and we’d always be pressed to show something. It was mostly academia, but a lot of companies used it as an advertisement for their instrumentation and we were always thinking about what we could show. And at this time I was quite closely associated with the Institute of Physics. So we decided we would show them our mini radar and then we had to think what we’d do. So we thought a simple thing we could do is have a train, everyone likes trains at exhibitions. I mean it's boys with toys isn't it? So we got a train and we got it moving up and down the track and all we did is we put a mini radar, I'm not sure whether the mini radar was on the train, it was on the train or on the track. I suspect it was, we had one at each end of the track. And as the train approached it would give a bigger signal with its reflection and when it got above a certain level we just would, through a relay, reverse the train. So we had a length of train with nothing at the end and the train never came off the track, it just went up and down and mysteriously it would know when to move and of course, because it’s a radar set you can put it in all kinds of things and there clearly was no light beam or anything and there clearly was nothing on the track, so, why does the train not go off the end. And I expect it was the train that got a lot of the publicity, but people were intrigued at the size of a radar set.

What sort of reactions did you get to it?

Oh, they were all favourable. Everyone was very happy, wanted to know more about it. The whole of the radar thing was very successful. We got very good publicity all the time through and it was a very nice in between thing. I’ve already said that there were three companies, British
companies, marketing devices, they were all happy with selling the things. I think they did reduce the price after a time. It was being used, it still is being used. I mean the device is really so simple if you think about it. There’s no junctions in it, it’s just a piece of semiconductor, you have a piece of semiconductor that is three microns – er sorry, ten microns – thick, you have a contact on each side of the thing and you put six volts, DC across it and lo and behold it gives out microwaves. Very mysterious. And it’s quite impossible to understand unless you know what goes on inside the semiconductor. You probably, you can do the same thing with a transistor now but of course it’s much more complicated and it’s quite a high frequency for a transistor, transistors work well in the kilohertz and megahertz range, but to try and get transistors working at gigahertz, it's not straightforward. So it’s a very simple way of doing this and as a result it was used for a long time. There is another device called the avalanche diode, which can be made in silicon and that also gives you microwaves. It’s much more complicated in the way in which it works, but essentially it takes a piece of silicon that’s got a p-n junction in it to the level where it breaks down, you use a higher voltage, a voltage enough to break it down, when it breaks down. I suspect that its life would not be quite as long as the transferred electron device.

[25:50]

You’ve talked about quite a few different applications for using the microwave radar in different forms – door openers, radar guns. Where did...

Traffic signals. We thought of that one. Instead of having pads in the road – you don’t see pads in the road any more. You used to see pads in the road as you approached traffic signals, that was to tell the traffic signal that you were coming. That of course is quite complicated and expensive to dig up the road and put pads in and they wear out. Now if you look carefully you’ll see above the traffic light a little box and that’s almost certainly a Doppler radar. It’s not the only way of doing it, but it’s almost certainly a Doppler radar.

Where do these ideas for applications come from? Were you generating themselves or were they coming from elsewhere?

Both ways. You generate them yourself, but of course that’s one of the functions of these exhibitions where you show things out, away, and also of the press notices that you get there and they tend to recirculate that they’re in papers and things and people write in or companies will come and visit you. We used to get lots of visitors who would come and they’d say I want to
consult you on this and talk to you about it. You’d talk to them and at the end they would say, ‘Now do I have to pay a fee for this?’ And I would say, ‘No, you’ve already paid’. And they would say, ‘Already paid? When did I pay?’ I say, ‘In your taxes. Your taxes cover this’. And they’d look at you and say, ‘That’s the first time anyone’s ever suggested my taxes pay for anything!’ But they’d go away quite pleased that they were getting this information free, and they did, I mean let’s face it, that we never denied anyone access, there was nobody who ever wanted to come to Malvern or Baldock – you mentioned secrecy and things – there was never any suggestion. If anyone wrote in, of a British company, actually I suppose even of other countries too, and wanted to come, we would always find time to see them. They wouldn’t always see me but we had a number of pretty competent people who would see them and deal with them politely and efficiently and occasionally they would tell me of this and some people I saw myself. But we got lots of post coming in from people [28:20] with ideas and things and from organisations. One of the applications at Baldock actually came from British Rail, but I don’t even think it was British Rail at the time. They wanted a device for stopping trains and they had read, either read our papers on indium antimonide for sensing magnetic fields, or had seen something in an exhibition about it. Either was quite possible. And they came and said they had this system for traffic control which consists of two magnets – do you know the way in which that works? If you look carefully you can see it. I think they still have it actually. But as the train goes along, as it approaches a signal it goes over a permanent magnet and that permanent magnet moves a rocker arm to one position, then after a short distance it goes over an electromagnet, which is either on or off. If it’s on then it brings the rocker back to the neutral position. If it’s off, after a certain time then nothing happens so it knows the signal is at danger or something, and there’s an indicator in the driver’s cabin which tells him to now stop and if he doesn’t, automatically a horn goes and if he doesn’t act then, then the train is automatically stopped. And that’s, it was called automatic train control. And they wanted to know if – they were a bit concerned about this rocker moving, because it’s mechanical and they were worried that it might stick or not work properly sometime and they said can we detect this thing electronically, and we said well, we’re pretty certain we can, because we knew we could detect the earth’s magnetic field so we were pretty certain we could detect something that was a permanent magnet or anything. So we made a device, this was at Baldock of course, we made a device that went underneath the train and sensed this. And one of the things it had to do, they said, was to stop a train that was going faster than 200 miles an hour. We said, ‘You don’t have any trains that go at 200 miles an hour. The fastest is 125’. They said, ‘Oh yes, but we’ve got to have a system that can cope with faster trains that we are going to have at some stage’. So we
said all right. And they said also it’s got to stop the train going at zero speed. We said, ‘Train at
zero speed is stopped’. And they said, ‘No it isn’t. A train is stopped when the driver has taken
the action to stop the train. He may have slowed the train down so that it is going very slowly
and slowly could be zero, but it’s not actually stopped and the system must work even though the
train has stopped’. Now that of course was quite important to some systems that might work
because any induction system that they could have would rely on the train moving across the
magnet. This sets up a current, whereas if it goes very, very slowly it won’t. We said no, ours
will work at any speed. We will measure the fastest speed it can go at, but there’s no problem
with slow speeds, it will go at zero speed. And in fact we showed it would go at 200 miles an
hour. So, and then they said it’s got to fail safe, no matter how it brakes, it must then give you a
positive signal. So we designed it so that if our crystal broke, which we didn’t expect it to do, but
if it broke [32:30] you would get a warning and it would all work. And we had various rides and
I had a very nice ride going up, it was very funny, I was going from Hitchin, they were going to
put us on a train from Kings Cross going up through Hitchin to Newark I think, and then back
again. And they said oh, we’ll pick you up at Hitchin, which was where I lived. So I went to the
station and went on and they came out, looked at me, said, ‘What train are you waiting for?’ I
said, ‘A train’s going to stop in a minute’. And they said, ‘We haven’t got a train stopping’. I
said, ‘Oh yes you have’. The train came along and stopped to pick me up. The station master
came out not knowing quite what was going on here, and he put his top hat on carefully because
he could think, he didn’t know, was this royalty or something it was stopping… it was just me.
So I got on this train and we set off and it worked beautifully. But in the end the reason why the
system failed is they wanted to use it over the whole network and they had a problem with
Southern Rail with the, because the electric system for Southern Rail is actually underground, it’s
like a tube system. Most of the electric systems are up above and you’re not bothered by the field
that comes in from there, but with the rail system that was used, at any time the train went across
it, it got a signal from the magnetic field, so they never adopted it. But I gave you this as an
example of how we were in touch with people and how – now we wouldn’t have known anything
about that, they got in touch with us. And it was the same with some of the other things. [34:25]
We had to do things like in airports and things, detecting guns and all kinds of things and we had
systems for doing that, and all that kind of thing. So we’d get approached by a number of people
to keep our feet on the ground. And we were in that area that we were doing basic physics, you
couldn’t get much more basic than sort of analysing where electrons were moving and
semiconductors and knowing about the quantum physics of this with our theoretical physics
department to making oscillators to working with people making radar systems. So it was a complete mix.

*With the sort of changes that were happening in the scientific Civil Service in the 1960s, white heat to get military technology into domestic things, did that actually make any difference to what you were doing already?*

Well, there are two things to say about that. The first thing is I mentioned that we changed in our Ministry a few times and people said to me, isn’t it difficult when you change a Ministry because you have to change your programme. And I said you don’t change your programme because you change a Ministry. [pause to check phone] You don’t change your Ministry, you change your description of what you’re doing just because you change – I was saying you don’t change the programme, you change the description. And essentially that’s more or less what we did because we were doing things that were for everyone. When we worked on thermal imaging, thermal imaging clearly is of great importance to the military but there are many applications of thermal imaging in civil life, even in the early days of thermal imaging before we actually had got high sensitivity, I was approached by, I think it was either a chemical company or the gas board who had a problem with one of the containers that held their hot gases and they were a bit worried about it because somehow they said it was leaking and they didn’t know where. And I took an image converter up to show them and could show them quite clearly there was a crack in the lining. I mean you just could see it through the image converter. They were immediately taken and started thinking about how they could order them and get them and use them. And this was fairly standard, that we were a hotbed of knowledge. And there were some things obviously that we couldn’t do, but we were widely consulted on things.

*What was the second thing?*

I forget. Why did I say there was…

*I was asking you what difference, you know, things like the white heat of technology and all that stuff actually made.*
Oh. Oh well that, of course the white heat, that’s a, and now that’s an important part of the story that puts us on a different kilter and we will have to deal with that in detail, that started in ’68. But do you want – this is a reasonable time, do you want to see the small radar set?

Yeah, sounds good.

Right.

Does it still work?

Does it still work? Well, it would if I put the batteries in, but I don’t keep the batteries in.
I think it was ’67 or ’68, somewhere round there, there was the change in government and we had the white hot technological revolution, as a result of which they decided that the government research establishments, or at least some of them, should be used to really improve industrial productivity and get things in, to get ideas into industry. And we were put into the Ministry of Technology and the Secretary of State was Tony Benn and he came down to see us. He wasn’t very popular because he couldn’t understand how the system worked and didn’t see why the police on the gate and the messengers didn’t have more input into the programme. Yeah, he somehow thought this should be done democratically. I mean the laughter that went around the hall, including from the messengers and the police, was such that he probably decided he was never going to come there again, and he didn’t. But we had a more productive visit from John Stonehouse. Now, that name may come to you because of things that happened later, and we will deal with those later if you like, if you remember them. He became Postmaster General, but at this time he was Minister for Technology and he came down to see what was going on in the place. And he spent some time visiting but most of his time he was talking to our Director, George Macfarlane. George was a mathematician and theoretical physicist who now was running Malvern, running it very well. He was a very, very good scientist and obviously I knew him pretty well. And he told Stonehouse that although there’d been a bit of fuss over Concorde being developed and the money being spent on it, most people didn’t appreciate how much money the lack of science was costing the country. And Stonehouse asked for an example and he said, ‘Well, for example, colour television. It’s not appreciated that we pay licence fees to American companies; the Radio Corporation of America, RCA, for the invention of the colour tube which is being made in Chelmsford but we have to pay a licence fee on every tube, every television set that’s made and over time we are giving more to RCA than we’re spending on Concorde’. I do not know where he got that number from. I think, I suspect that I said it to him some time and I do not know where I got it from, but it’s one of these numbers that comes in and it’s very useful in conversation even if it’s incorrect, because it attracts attention. There was a lot of money, I mean there’s no question, there was a lot of money being spent and there’s no question of it because we know how much money RCA was earning from colour television and a fair slice of it would have come from the UK. Anyway he said this, he threw this into the conversation. He told me this, that’s how I know it. The next morning apparently, Stonehouse rang him and said, ‘Director, you’ve convinced me. We definitely ought to do it’. And George had had a long conversation with him, so he said – he was a good civil servant – he said, ‘Oh well that is good
news Minister, that is good news, I’m very pleased. Which particular aspect of our work were you meaning?”, because we did so many things. He said, ‘The need for a flat panel display, of course’. He said, ‘Start a programme on this, we must, must get away from this stranglehold which the American company has over us, so can you please start a programme’. George immediately summoned the Head of Physics, David Parkinson, who was a low temperature physicist, again a very, very good scientist, very nice man, down to – and me – down to his office and told us what had happened. And he said to me, ‘Cyril, what can we do on flat panel displays?’ I said, ‘Nothing’. He said, ‘Nothing?’ I said, ‘Well’, I said, ‘we can make some LEDs’. He said, ‘I don’t think that would do’. So David said, ‘Well, we could have a working party’. And George said, ‘Good idea, we’ll have a working party on it’. So he was immediately able to report to John Stonehouse that we were starting on this and we’d got a working party working on it. So David set up a working party on it which obviously included me and included good scientists from different disciplines within Malvern. [05:50] And then, bless his heart, he got promoted to headquarters and came into my office and threw a file on my desk and said, ‘It’s all yours Cyril’. I said, ‘What’s mine, David?’ He said, ‘The working party on displays, it’s yours now’. I said, ‘Oh thanks’. So I then had to tell the people that now I was chairman and we needed to get something done on this, so we all put in our bits of what should be done, we looked at different physical concepts, different ideas on how you made flat panel displays. Spent a lot of time on it, did quite a lot of work, and wrote a report. And one Sunday I was sitting in my garden reading the report, knowing that on Monday we then had to approve the report. And the report said that we’d analysed all the different things that could be done and we had decided that we would work, start programmes through CVD, which we’ve mentioned, on two topics. Ninety per cent of our effort would go on ferroelectric ceramics and ten per cent would go on liquid crystals. Now, you’ve never heard of ferroelectric ceramics? No. And you never will. It was a system which Bell Labs had been working on which worked at quite a high voltage, so a hundred volts, and was a slab of material made in a certain way and it changed in its transmission when you applied an electric field and in principle it could give you a display. You have heard of liquid crystals? Right. So I read through this report and I didn’t like it and I was uncomfortable with it. So I read it again and I started doodling and then wherever it said ferroelectric ceramics I crossed it out and wrote liquid crystals and wherever it said liquid crystals I put in ferroelectric ceramics. I took the report back and gave it to my secretary on the Monday morning and said, ‘Gwen’ – I think it was Gwen then – ‘Can you please change this over on those pages for our meeting this afternoon’. So it was changed, and I know it was changed and I can prove it was changed because we’ve got photographs that clearly show that the secretary had not used quite the same
printing for it, so it stands out that the change was made. And I presented it to the working party and they read it through and looked at me, read it again, said, ‘You’ve changed it’. I said, ‘Yes’. And they said, ‘Why have you changed it?’ I said, ‘Because it didn’t read right. It didn’t read right, it wasn’t right’.

_In what sense ‘read right’?_

That’s been a matter of some debate over the years as to why I changed it. Now everyone agrees that it was ridiculous in its original form because ferroelectric ceramics have vanished, nobody’s ever exploited them, they were far too difficult and obviously everyone’s exploited liquid crystals. So why? And I suppose that what I thought, I’m not saying it was instinct or intuition, I think it was based on experience and things and I thought that we were prejudiced against liquid crystals because they were liquids. Nobody had ever done anything with liquids of any importance. The physics was not well known, the materials certainly weren’t known and we had all the problems, how did you contain them and deal with that. But I was attracted with the fact that it worked off low voltage. Now, of course you can say that I was conditioned by what we’d done with the microwave radar, that it worked off low voltage, but I’d certainly shown that that was extremely important and was becoming more and more important as… [interruption – pause]

[11:00]

You were talking about low voltages, or the importance of them.

Yeah. We were moving into semiconductors. This came later on when we were doing some other displays, but we really had to consider a complete system and we knew at the backs of our mind that we were doing this that any system would have to work with semiconductor integrated circuits and the kind of voltages people were thinking of were twelve volts or something like that, not seventy or eighty. This came in later as well when we were dealing with electroluminescent displays for cars, and would be a complication. So that was one of the things. And we were dealing with two systems and we knew nothing about either of the systems, so it was a question of which way did you go. And at the time I thought liquid crystals really deserved more emphasis than the ferroelectric ceramics. Didn’t mean to say we were ruling out ferroelectric ceramics; we said ninety per cent/ten per cent. So I think the working party was a bit fed up with me but they’d been working on it for six months and it wasn’t their own primary interest, they
had their own things they were doing, and I suppose they thought well, if that’s what you want, that’s what you get, so it’s up to you.

Why a ninety-ten per cent split, not fifty-fifty?

No, no, no, no. We wanted, we knew that we had to declare we were working on something that we were going to do and we were going to have a saver – actually it didn’t work out like that at all in the end because we worked on a number of different things and we didn’t do ninety-ten, but that was originally what we said. And we said we should also investigate the various other things that were possible, and there were a number that we did in a small way: electrophoretics and electrochromics and we did work on a number of other things in a small way with pilot programmes. But essentially it was going to be a liquid crystal programme.

[13:40]
Just a little bit more on the background of this as well. Why flat panel displays at all?

Because one of the real problems of the cathode ray tube was its geometry and that became more and more significant as you made a bigger system, because as you made the bigger system you couldn’t really avoid making it deeper, that you couldn’t get electrons to go round very sharp angles so you couldn’t think of just taking a small cathode ray tube that was perhaps six inches long, six inches deep and then making the screen bigger, because you couldn’t bend the electrons that far, so you had to make it deeper. So if you wanted a large display it was going to be essentially in a rectangular box, whose dimensions were about the size of the visual area. In other words, if you wanted to have something that was one foot square, it would have to be one foot deep as well and that meant it all got bigger and bigger. So it didn’t matter for a small thing, it was a bit of a nuisance, but it was so much more compatible with the design of the system that you had one side of the box that was going to be your display and then you’d have something a few inches deep in which you could put everything else, because everything was getting smaller, all of the circuits. You were getting away from valves and things, it wasn’t just the display and getting rid of the cathode ray tube, you were already moving towards getting away from valves and going on to integrated circuits. And they weren’t that integrated then, but transistors were flat, if you compared the size of a transistor with that of a vacuum tube, it was one-dimensional, basically. Well, two-dimensional, not the third dimension. So everything was moving towards that. And of course, even in the literature you were talking about television sets on the wall and
not wasting space in your house and things, and all of that was correct. The cathode ray tube was actually a great nuisance in the design of a complete system, in voltage, in depth and also in the fact that as you put it, as you made it bigger it was going to weigh much more. I think I did tell you about the explosion I had when I was working on the transmission of the atmosphere and evacuated a container to measure heavy water absorption and said it broke because of this relationship between the thickness of the wall and the pressure you put on it. Well that applies just as much to a cathode ray tube, even though it doesn’t have to be quite flat, you can make it curved if you’re going to make a really big television like forty inches across, which people do, then the thickness of glass that you need to be safe as the front panel has to be considerable, it’s got to withstand that pressure, because you’re evacuating it. And that starts putting up the weight enormously. So the whole thing meant that the advantages of a flat panel were considerable and the weight thing was important for the military. [17:55] And people used to manage with small displays because they had to use a cathode ray tube.

What sort of applications were you anticipating for liquid crystal displays back in the 1960s? What were the main ones on your mind?

Well, that depended on who I was talking to. One thing Sutton did teach me was that when you’re asked a question you first of all try and work out what the questioner, what agenda the questioner is following. So if I was asked by somebody in the military I would say, well we’re obviously interested in radar displays, and if you imagine an aircraft or a tank, then putting a reasonable sized display in is very difficult, and in fact it’s impossible in some circumstances, because you’re always short of room in military vehicles. I don’t know why that is, but you always are. I mean you can’t put things there, you put the actual people in very difficult situations because there isn’t much room, and the same thing applies in the Navy as well, though you think there’s plenty of room on a ship you find that most of the room is taken up. So there are plenty of applications in defence. If, on the other hand, I’m talking to DTI, as I was later on, then again, I will point out all the civil applications there are. If I was talking to somebody in instrumentation I would just talk about all the instruments that you have and complications of design and how much simpler it would be. And the voltage is very important. So yeah, all those things. And I did actually produce… [telephone ringing] That the… [telephone ringing]
But I will say that I did in my talks on displays, which I must have given to funding authorities as well as other people, I did show what was happening in the display world and what was going to happen in the future and how different technologies could play different parts in this. These got better as time went on, obviously. But I was very conscious as to the markets for things. I suppose I could see at some time in the future, which I would laughingly think of as fifteen to twenty years, the things we chose might become important and might even have a share in the market. I don’t suppose I ever thought at that time – remember this is ‘68/69 – that we were going to replace cathode ray tubes. But I could see that there would be commercial markets for the things.

Did you ever foresee the rather massive liquid crystal display TV on the wall behind me?

No, I never thought that far ahead. I don’t know that I ever really thought too much about where it was going. I was swept along by the enthusiasm for doing something new. I got more enthusiastic about liquid crystals as time went by. I was quite uncertain. I may have seemed confident then to the people, but I was very conscious of the risks that we were taking.

What were the risks?

It was all going to come to a crushing halt and we wouldn’t be able to get there, and there were many times later on when it did look like that.

I suspect liquid crystals in detail are going to be a topic for next time, but could you very, very briefly explain to me the principles behind how a liquid crystal display actually works. And let’s assume I’m completely ignorant about such matters, which as always is probably not that far from the truth.

Well, liquid crystal of course, as the name indicates, is a liquid that has some order. The difference between a liquid and a solid is that if you look into a solid you can, with enough magnification, see where the atoms are. In a liquid crystal the atoms are bound together in molecules which are usually quite long molecules, quite long series of molecules, particularly in organic materials. And they move around, they don’t have any position that they will take
because in a liquid everything is moving, it doesn’t have a position, you can’t give it an address and say that that particular molecule I will put a tag on and that is one inch from the left-hand side and four inches from the right-hand side – no – one inch from the left-hand side, four inches from the bottom and three inches in from the back wall, and I’ll come back tomorrow and see where it’s got to. If I did that in a solid I would find the same atom in the same place, I mean that’s what a solid is. You come to a liquid and there’s no relationship between where the atoms are one day and where they are the next day. So that’s the first point about the liquid. And also there is no relationship between the position of one molecule and the position of another molecule at that time, that one moment they’ll be a micron apart and in ten minutes they could be three inches apart, they could be anywhere. Whereas in a solid they’re there, there’s that atom, number one, there’s that atom, number two, and they’re there today, they’ll be there tomorrow and next year they’ll also be in the same place. That’s a solid. Now when you get a crystalline solid there’s even more in that because there’s a pattern, there is a relationship between the position of two atoms that is both in distance and in angle and there are various patterns that you have in different crystal families. The simplest is a cube where the atoms are at the corners of a cube and if you have a single crystal, which is crystalline, that crystal is all the way through, there is a cubic structure that goes throughout the whole solid. They may be all of the same type of atom so that all of the corners have the same atom. Sometimes you have a face-centred cube in which you have extra atoms at the centre of each face, sometimes you have body centred cube on which the atoms are at the real centre of the cube. And there are a number of crystal families and of course if you have more than one atom, more than one type of atom, then they have different configurations and the configuration they take up determines the properties, though the actual crystal structure may be the same for two configurations. And defining the atoms does not necessarily define the crystal structure that you get. Sometimes crystals take different structures, depends on how they freeze as to which structure they’re going to adopt. And then you also get some very interesting systems which are effectively glasses, where it’s a solid but there is no simple relationship between the positions of the atoms, though there may be some preference for atoms to be a certain distance from each other. And that is called an amorphous material and later on we will get to amorphous silicon, which is different from the normal crystalline silicon, which is the basis of integrated circuits. Now, silicon and germanium have the same crystal structure, which is the same crystal structure as one form of carbon. But that form of carbon is the most expensive form, it’s called diamond and that structure is called a diamond structure, which is related to the cubic structure but there is a hexagonal feature about it too. But carbon can take different forms, it doesn’t always have the same form, and it’s not certain that when you take
some diamond – sorry – take some carbon atoms and heat them up and cool it, it’s going to form a diamond. Pity. And in fact people have found some ways of doing this so that when they do heat carbon up and then cool the mixture down that they do get diamonds, usually not very large diamonds unfortunately, but they get industrial diamonds now. [08:05] But that’s something they’ve learned how to do over many years. But if you take silicon or germanium and heat them up as you do to make crystals and let them cool down, you will always get the same form of crystal. You may not get the orientation of that cube exactly right over the whole solid that comes from a melt, and there’s some skill in which you freeze that melt so that you do get one crystal, so that you can identify directions which continue throughout the whole boule that you have made. But you have to know what you’re doing in order to get that happening. If you just took some silicon, or let’s say you took a pile of sand and you heated it up so all the oxygen boiled off, which you can do, boiled off and then let it cool and you didn’t know what you were doing, you would get a boule at the end but it would not be a single crystal of silicon. It would be a boule that had hundreds, if not thousands, of tiny little crystals of silicon, each one of which was this perfect crystal, but few were aligned with each other. And that is one of the things that people learnt how to do, how to actually make a boule as one crystal. And now they can do this with silicon crystals that are tens of centimetres across, if not metres across, huge boules of silicon that are one crystal from which you can make many, many, many integrated circuits. It’s one of the things we’ve learnt to do and it’s one of the things which now is being done for solar cells, that they’ve learned how to take boules and freeze them so that at least over ninety or ninety per cent of the volume is all just one crystal and then as you get to the edges of the boule, you get the polycrystals. So that’s where you get the secret of how to exploit the material so as to ensure that the physics you’ve learnt on the material is carried through into a device. And the same applies to gallium arsenide or indium phosphide, the materials we’ve talked about, indium antimonide, and it won’t surprise you to know that the lower the melting point the easier it is to make the single crystals, but in general it’s pretty easy to make indium antimonide single crystals. It’s more difficult to make gallium arsenide, more difficult still to make indium phosphide. And any compound semiconductor, particularly one with a high vapour pressure and, no, I shouldn’t say any. Those with a higher melting point are more difficult to make single crystals of than silicon and germanium. And this of course was one of the points about when people were moving from germanium to silicon, that people started with germanium transistors, realised that there was a problem here with the temperature at which you could operate the transistor once it got above sixty degrees centigrade, which it could readily do if you were driving it quite hard with a high current, its properties began to get less favourable because it has a lower energy gap. And of
course you’ll appreciate that there is a link between the energy gap and the melting point, that as you want to go to a higher energy in the material in its transitions, it’s not surprising that a higher energy is needed to form the material, so the melting point gets higher and silicon has a melting point that’s much higher than germanium. So it wasn’t a triviality when people said germanium’s not working properly, it’s a semiconductor and a good semiconductor but we want something with a higher energy gap, let’s just go to silicon, you couldn’t just do that. You had to then work out how do you purify it, which becomes more difficult because if you go to higher melting points you’re operating at higher temperatures which means you’re likely to get more impurities coming in from the materials that you’re melting the silicon in. That’s the first thing. And the next thing is that you’re more likely to get it crystallising as multiple crystals rather than single ones. You get over this by having a seed and that you freeze the material from a seed that is a single crystal, and you can imagine having a small seed and the material solidifying on that seed slowly and carefully with very few temperature variations so that the crystal grows on the seed and as it grows and gets bigger it keeps the crystal form. And of course then you will say if you think deeply about it, but how do you start, how do you get the first seed, you’ve got to be lucky. You really have to be lucky. You do freeze your material slowly and you inspect it carefully and you know you’ve got lots and lots of crystals at the beginning, and some of them are big enough for you to do your experiments on, which indicates that this is a good thing for you to be working on, so you want bigger crystals, and you gradually extract bigger and bigger pieces of crystal that you then can use as a seed. Or you’ve got a friend who’s got one and he lends it to you, because of course you don’t use up the seed, you don’t melt the seed. You’ve got to be careful, if you melt the seed you’re back to square one. So you have to ensure that your seed is held in something which keeps it cold and then you grow the crystal on it. And if you’ve grown the crystal on it you’ve then got a lot of seeds. So if you’ve borrowed the seed from a friend you can give him back his seed because now you’ve got your own seeds. And that’s how you do it.

What does the seed actually look like?

Just a piece of material, though usually you have polished, you’ve sawn the edges so it’s a rectangular column, so you can hold it in something, in a chuck. So you have a rectangular piece of semiconductor that just looks like a semiconductor, vaguely like a metal, though it’s usually a bit more bluish than most metals, and it will be perhaps five millimetres square by about a centimetre long. But you may have to start out with something that’s a bit smaller than that in order to grow one. But that’s what you would normally work with later on and it has to be a
reasonable length because you do have to melt the end of it in order to grow something on it and of course once you’ve grown something on it, then you’re laughing, you can now cut whatever you want from it.

[16:00]

*So the material inside say, a complete screen, it is just one crystal?*

Ah, we haven’t got on to liquid crystals.

*Right, okay.*

We’ve only got on to solids.

*I thought I’d missed something here. Right, that’s good.*

Now, I got diverted because you asked me what a crystal was like and that was a solid crystal. Now, a liquid crystal isn’t quite like that because it’s a liquid. But you now have to imagine the molecules of the liquid crystal as being cylinders, small cylinders and normally if you put a liquid crystal in a test-tube, it would look cloudy, you couldn’t see through it. And the reason for that is that the different cylinders are dispersed at different angles, they bear no relationship to each other. So the properties of each cylinder are that they are transparent, but they have quite a high refractive index and the refractive index will be different along the axis of the cylinder and across it. But in this test-tube light falls on one of the cylinders and will be scattered from it to the next cylinder and because there is no relationship between them, then the whole material will scatter light, it won’t transmit it in the sense that glass transmits it. But now you can do things with a liquid crystal which are unusual in liquids. You can actually get those cylinders to lie down on a glass surface. Or you can get them to stand up from a glass surface, or you can get them to be at an angle from the glass surface, but to be at a definite angle to the glass surface. And how you do that depends on the way in which you’ve treated the glass. The simplest way in which you can treat the glass is to rub it. But you must rub it in the same direction all the time. You just take a piece of cotton wool and you rub it from right to left and then you lift up the piece of cotton wool and you rub it again from right to left in the same direction. And now if you pour your liquid crystals on it, those near the surface will all lie down in the way in which you rubbed it. Now of course if you varied the direction of rubbing they won’t know what the hell you intended will
they, so they'll be in all directions, but if you've been sensible and rubbed it all in the same direction, then they will all lie down in that direction. Or alternatively, there are treatments you can give the glass that mean all the things stand up from the glass in the same direction. So now imagine that I've got two pieces of glass which I have treated, and I've given you a very simple example, so let's assume that I have rubbed the pieces of glass in the same direction – it doesn't matter direction, left to right or right to left, it's the angle at which you've done it – and if those two surfaces have been rubbed in the same direction or I put them together so that that direction is the same on both of those surfaces, then all of the liquid crystals in that material will follow that direction. And that is actually a nematic liquid crystal, that's the way in which it wants to go. Now, nematic liquid crystals have the property that the molecules want to line up with each other, that all the molecules want to point in the same direction, but if you put a nematic liquid crystal into a test tube, you haven't told it which direction you want it to be in. So although in a small volume they're all pointing in the same way, if you actually look at that volume in the test tube, that direction has varied, which is why now the material is scattering. Now by the action of controlling the alignment, which is what we did by doing this, I've now made material which is transparent, and I can see through it. Similarly, if I actually define that direction by having the direction orthogonal to those glass walls, again, all of the liquid crystals would be sticking out from one surface to the other, so again it would be transparent. It would be a different kind of order, but you can see there's some kind of crystallinity. The difference between this kind of crystallinity and the silicon germanium, gallium arsenide kind of crystallinity is you could define in those a distance between the sides of the cube, the distance between the atoms. It is a fixed distance and will be the same throughout the crystal, absolutely exactly the same. No difference at all. But with this kind of liquid crystal I haven't defined exactly the distance between those cylinders that are lying down. I might have done, I could have done if I'd been extremely careful in the way in which I made those movements across, but all I did is I rubbed it in one direction. Now if I'd been extremely careful and had a very tiny piece of cotton wool and I'd rubbed it and then had moved it by one micron and then moved it by another one micron and then moved it by another one micron, then I might have actually got a fixed distance between them. But I wouldn't normally have that. So the nematic liquid crystal, although it has a preferred direction which I can exploit when I'm aligning them on a glass surface, it doesn't have this distance. On the other hand, there is a liquid crystal form called the smectic liquid crystal where there is a kind of lattice like that where there is actually a distance between them. That's the nearest thing we have to a single crystal, but of course it gets a bit confusing when I try and align it. But the smectic liquid crystal does not have the applications that nematic has. Then there's a third form
of liquid crystal called the cholesteric liquid crystal where you do have a preferred direction for these cylinders, but that direction is on a helix, so the direction changes as you move from one part of the crystal to another in a preferred way. So there is a kind of distance between the molecules and you can imagine the helix building up and you can have ways of actually having that access of the helix pointing into a definite direction. That gives you a different interesting structure because the actual distance between the layers in the helix can be similar to the wavelength of light, so you get reflection from the different parts of the helix and you get colours and that cholesteric material is exploited in thermometers, because you get a reflection from the planes of the helix and that distance between those is temperature sensitive if you choose the cholesteric right. So you can get the colour changing with the temperature, which means that you have made a thermometer. [25:50] And people have used thermometers. But we’re getting away from the standard liquid crystal that is used in most displays, there are some which exploit other forms, which is the nematic liquid crystal. So you have to imagine that in the first place we’re starting out with two glass surfaces on which we have actually established a direction of alignment and in the simple example I gave you, that direction of alignment was the same on each of the surfaces. [telephone ringing] [pause]

[26:34]
Okay.

Talking about the two…

Yes, I know. But now you have to think about the way in which these cylinders react with light and they have a way of trapping light in them, which is not one which absorbs the light, as you can think of it as holding the light and then letting it go, but letting it go with some relationship to the angle at which the cylinder is. We took the simplest structure with two surfaces in which that alignment direction was the same. Now imagine a situation where we have turned one of those walls by ninety degrees and now we have a structure in which the angle that the nematic material is lying on the surface is now having to cope with another surface, not that far away, a few microns away, in which the preferred direction is at ninety degrees. And what happens is that essentially you have built in a twist in the cell, you have now made a twisted nematic cell in which that preferred direction is changing progressively from one surface to the other. We now have to think about light as an electromagnetic vibration and in any kind of vibration you can have a predicted direction in it. If you think about a water wave on the surface, you can imagine
there’s a direction in which that wave is travelling and at right angles to that, you have a direction where the depth of the water is changing and you can now think about having two directions at right angles to each other of the water waves and you think about that and say well, are they different in their nature. Well they’re not really different unless you know what that direction is and with electromagnetic radiation you can think about a direction of propagation in which the light is going from one place to another place, but you think about what way the electromagnetic forces are varying as you go orthogonally to that. And in fact the electromagnetic forces are changing in that direction, regularly. So you can now divide those forces, the direction of those forces into forces in one direction that is perpendicular to the direction of propagation and another direction which is perpendicular to both of those. In other words think about three directions: we have one going from your source to your receiver and then we have two other directions orthogonal to that. And they are called the directions of polarisation, that we have vibration which is in one direction, vibration that is in another direction, and we can divide any arbitrary light beam into those two directions, but normally they aren’t divided, they are going in both directions at the same time. But we can divide those. We could, for example, put that light through a barred gate. Imagine trying to put that light through a barred gate, like you have sometimes at the entrance to a field. Of course if you put the light through a barred gate, that that hit the bars would not go through and that that went through the gaps between would go through, of course it did. But now put the bars closer together and make them narrower. Keep on doing that until you’ve got a bar, a series of bars that are all in one direction, obviously. All those bars are the same and they are about the same width as the wavelength of light and the spacing between them is also that of the wavelength of light. It doesn’t take a great deal of imagination to imagine that the light that was vibrating parallel to the bars of the gate will go through and the light that was perpendicular, orthogonal vibrating will not go through. And that in fact is what does happen. We don’t have a gate but we can make a grating that is of those dimensions. It’s clearly not easy to make, but we know how to do it and you can do it photographically. And the bars don’t actually have to be opaque, they don’t have to be of wood, and it would be quite difficult to make them of wood, but imagine them being made of glass. We could do that and the refractive index would cause changes. And we actually can do it with something that’s very common to people, it’s used in sunglasses, it’s called polaroid and what you have with polaroid is a material which won’t let light through that has one direction of vibration but will let light through in another direction of polarisation, and that’s how we polarise light. Now let’s take your two pieces of your sunglass that you’ve got and put them one over the other. Well, polarised light will go through, will come out from one side and that of course will immediately go through the
other side, I mean you may lose some intensity but it’s going to actually go through both because
the polarised direction, the preferred direction is the same on both halves. But I’m going to be
clever now, I’m going to twist one of those through ninety degrees and what happens? Well, the
light that’s polarised by the first one is polarised in one direction and that’s not the direction
which the other part lets through, so no light gets through. No light, however it’s polarised, will
get through, even though I have two polarisers which are supposed to let around fifty per cent of
the light through. [33:50] Pity. Now what’s happening in the liquid crystal? Let’s think about
the liquid crystal. The liquid crystal, we have said if you remember, actually gives a twist in the
direction of polarisation of the light – it twists all of that light actually – but it certainly will twist
that direction of polarisation. So let’s take our one half of the sunglasses and put it so the
polarised direction is the same as the alignment direction was when we first rubbed this cell wall.
So the polariser will actually let through only the light that is in that direction and that direction is
now twisted by the liquid crystal, so it’s at ninety degrees to the original direction, but remember
that we took the second half of your sunglasses and put that there and that was twisted at ninety
degrees. So glory be, we’ve now put something in between those two pieces of sunglasses so that
fifty per cent of the light will go through and will come out at the other side. If I took the liquid
crystal away that wouldn’t happen. But I can take the liquid crystal away, I can take it away, I
actually can take it away. But I can do the same thing more cleverly. How do I do that? I rotate
the liquid crystal molecules so that instead of them lying on the surface, they now stick out from
the surface and of course if I can make all of them stick out from the surface, from both surfaces,
the twist has vanished. So I have an electronic way – or at least I have an electronic idea – for
actually getting rid of the twist that I put in. But how do I do that? Well, liquid crystals are kind
to you. Those molecules are actually charged at the two ends, or there’s an effective charge, so
liquid crystal molecules have a property I didn’t tell you about before. Those cylinders turn in an
electric field and there are two types of liquid crystal, they’re all nematics, there are positive
nematics where the cylinders will turn to lie along an electric field, and there are negative
nematics which turn to lie across the electric field. So I have to be careful in this device to use
positive ones. Now, although I said these were pieces of glass and I had rubbed them, what I
didn’t tell you was before I rubbed them I put down on them a layer of a material called indium
tin oxide which is a conductor that is transparent, so I can look through it, but indeed I can apply
an electric voltage between the two surfaces. So I’ve got this cell which looks harmless but
actually is quite complicated. It’s not just glass, it’s got glass with a conducting surface on the
inside surface, it’s been rubbed so that it’s got a preferred direction. That preferred direction is at
right angles for those two surfaces and now I know when I put my liquid crystal in and I apply a
few volts to it that all the molecules will turn so I can take the twist out, and that, my friends, is the twisted nematic effect and is the basis of many television sets.

[end of Track 17]
Well, we’ve now reached about 1970 and my world really divides now into two, which is
developments in semiconductors and developments in displays and though one is to some extent
linked with the other, the actual way in which they go is very different. So we will take on two
different threads and we’ll mingle them later on. So let’s continue the story of displays and
essentially what was happening was that we had a responsibility but no expertise, in that perhaps
wisely, perhaps unwisely, I had decided we would concentrate on liquid crystals and now I had to
organise it in a way that obviously exploited the talents that we had. And though naturally we
had some general ideas within our own establishment in Malvern as to what we wanted to do, we
still needed to extend outside, bring in the companies and find out who could help us on liquid
crystal development. So I was helped here by the CVD organisation which could see themselves
playing a part in this and they certainly wouldn’t want to be left out, and they said they would
clearly back contracts with people who were knowledgeable and would I kindly tell them who
was knowledgeable. So I arranged with the secretary of the appropriate committee, at that time I
don’t think we had a displays committee but we were prepared to set one up. And he called a
meeting in London where we tried to get all the people in the UK who claimed some knowledge
of liquid crystals, and that included most of the electronics companies. In fact, Marconi had
before the war done a little bit of work on liquid crystals. They had a couple of patents but they
hadn’t taken it seriously and the people who were involved no longer worked on liquid crystals.
Actually, one of them was now in a pretty senior post in the Ministry of Defence, but he wasn’t
prepared to do anything about liquid crystals any more.

Who was that?

Oh, I forget his name actually. His name is on the patent. But all of the companies wanted to be
in on the show so they all sent someone who no doubt had done a little bit of reading. There were
some people from universities and there were some people who came from other organisations
who really did know something about liquid crystals. And we arranged a programme and I
chaired it and we set up to do it. And the key speech was done by the person who was recognised
as the liquid crystal expert in the UK. And he gave what was quite a reasonable talk on liquid
crystals and what they were and what you could do with them. It didn’t include any display
information, it was a pure talk on the effects that you could see in liquid crystals, what materials
were and essentially what a liquid crystal was. And that was all fine and he finished his talk and
then I called for questions. And as often happens, as you know, nobody asks any questions. And if you’re chairman you feel that you almost owe it to the speaker that someone should declare some interest by asking a question, and usually it’s the chairman has to think of a question. Well this chairman couldn’t think of any question at the moment, but then I suddenly thought of something and I said, ‘Well the light from the slide projector…’ – you can tell how long ago this was, these were slide projectors - ‘the light from the slide projector is coming out and it falls on that sample of liquid crystals in a tube that you put down’. And he said, ‘Yes’. And I said, ‘And then it’s reflected on the screen and there’s a complicated pattern which is moving on the screen, how does that happen?’ And he said, ‘That’s a very good question, I’m very glad you asked that question and the answer is…’ and then he said, ‘And the answer is… no, no, that’s not the answer. No, no, that’s not the answer’. So we all agreed it wasn’t the answer, no, that wasn’t the answer. He said, ‘No, no, that’s not the answer either’. So we all nodded and thought no, that’s not the answer either. He said, ‘I know where the answer is. The answer’s in my notes’. And he had a file with lots of loose notes, so he said, ‘It’s here somewhere’. And he opened this book and he had all these loose notes and thumbed through them and said, ‘It’s not there. It’s further on in the notes, it’s here I’m sure’. And then he dropped the notes on the floor. Now, of course it’s quite an easy thing to do because he had a pretty small lectern on which everything was balanced and he just – including his liquid crystal sample, I will say – so everything fell on the floor and then he fell on the floor himself and grovelled, going through his notes muttering, saying, ‘It’s here somewhere, I know it’s here somewhere’. And everyone was getting embarrassed, me more than most, I felt the meeting was getting out of my control. I mean what do I do now? I’ve got this person sort of crawling on the floor in front of me and this seemed to me to be lasting for minutes. Of course it wasn’t, it was only a few seconds, but even so, there was my speaker on the floor, there was my audience waiting for the next talk and wondering what was going on. And then a quiet voice came from the back of the room saying, ‘I wonder if I can help you’. And I looked up and said, ‘I’d be most obliged if you would’. And he said, ‘Let me explain the pattern’. And he explained how the light fell on the nematic crystals which were threadlike and how their dielectric constant refractive index varies and as a result you got this scattering pattern and because you had the motion of the liquids, partly because it’s Brownian motion, normally, but also because he had put the thing down and the liquid was still stirring, and that’s why you got the variation in the pattern. I said thank you very much, that’s very good. Then what happened next is open to a bit of controversy because some people say I kicked the speaker on the floor. I think I just nudged him with my knee. Others say no, no you definitely, you kicked him. I nudged him with a knee and said, ‘It’s all right, we know the answer now’.
And he turned and said, ‘What? What?’ I said, ‘We’ve got the answer’. He said, ‘Oh good, good’. And he collected his notes and disappeared into obscurity. The meeting proceeded and the secretary, Leslie Large, at the end said, ‘Well have you made any decisions Cyril?’ I said, ‘Yes. Put…’ and I’m not saying the exact word I used now, ‘Put that gentleman under contract’. And that of course was George Gray of Hull University. Now, of course it wasn’t as simple as that because we hadn’t got any funding, we hadn’t got any approval, but we knew really what we wanted to do. [08:20] And it was very timely because George Gray had recently had the proposal for work on liquid crystals put up to the Science Research Council and the Chemistry Committee had refused it on the grounds there wasn’t sufficient research in it. We didn’t quite take that view, we thought George knew a great deal about liquid crystals and he was the person we wanted to work with and before long we managed to find enough money in CVD to actually place a contract with Hull University for the development of stable liquid crystals. And this was the munificent sum of £1,400 a year. And that would actually pay for the research, that was quite a reasonable contract. George was quite happy to work with us. So we set out to learn more about liquid crystals and George set out to make useful liquid crystals, and useful was quite specific, because the American effort had come to a crushing halt. [09:35] I don’t know whether I got to this in describing what had happened. So I need to go back a bit on why we had thought about liquid crystals. Now we weren’t the first people to have thought of using liquid crystals, that goes back many, many years, nearly a hundred years they were known. But they were pretty obscure materials. One of the points was that the form that was likely to be useful was only there above room temperature. The liquid crystal changes in its habits, you get different degrees of crystallinity depending on the temperature and any material will move through different phases and certainly will go through the phase of smectic liquid crystal, which is very organised, to a nematic crystal, which is less organised, until it becomes isotropic when it is really warm. And that nematic stage which is the one we felt was of most interest could occupy only a few centigrade degrees and usually above room temperature. The liquid crystal changes in its habits, you get different degrees of crystallinity depending on the temperature and any material will move through different phases and certainly will go through the phase of smectic liquid crystal, which is very organised, to a nematic crystal, which is less organised, until it becomes isotropic when it is really warm. And that nematic stage which is the one we felt was of most interest could occupy only a few centigrade degrees and usually above room temperature. And the standard material that was used at the time did operate above room temperature, so you’d have to heat your equipment in order to observe the optical effects. But the standard material that was used and was used by the early workers was called a Schiff’s base, which is a particular chemical formula, and this was prone to changes in its properties as it took in more oxygen and water vapour and you had to ensure it was pretty pure, otherwise it would not keep these properties for long. And long, I mean a week or so. Now, the first people who’d made a concerted effort to apply liquid crystals was the Radio Corporation of America, RCA, in Princeton. And a man there got interested and he actually showed some interesting optical effects. I have described some of these optical effects,
that if you take two pieces of glass and you put them parallel to each other a few microns away from each other, which you can do with spacers, and apply an electric field, you can get changes in the orientation, you can get them to lie down on the surface or stand up from the surface and you can change that by putting an electric field on which with that spacing, a few volts will give you a change. Now, you have to use alternating current because the liquid crystal will decompose due to electrochemical effects if you use direct current, but that’s all right, the alternating current works perfectly well. Now, RCA had been interested in the effects that you could get, but they couldn’t get a very good optical effect that you could see, and then the leader of the group, together with some others, discovered an effect and this was called dynamic scattering. And you got this by adding ions to the liquid crystal. Liquid crystal is normally non-conductive, there is nothing in there which gives you conductivity. But if you add ions you can get them to form in a cloud and they can, with the liquid crystal, give a scattering effect so that you actually get the material in this cell looking cloudy and light does not go through, and then if you apply an electric field you can disperse that cloud so the material becomes transparent. And RCA thought this was a very interesting effect which they could exploit and they did actually make some simple numeric displays and they were encouraged enough to want to try and take this further and make a display with a large number of picture elements. Now, the concept of a picture element is quite useful here in that the display will be divided into many hundreds or even thousands of picture elements and by controlling a single picture element and multiplying the effects, you can get a numeric form or an alphanumeric form with a message, or a picture display, and of course you might be able to put colours on as well. So this is the basis for a television set, essentially, and that is very complicated and will involve over a million picture elements or pixels to get a reasonable picture. And you can appreciate that because you will remember at some stage that you have 625 lines on the picture, it used to be 400 and something, but we then moved over to 625 and those are the horizontal lines and then you have at least an equivalent number coming vertically down, so you will have well over a million picture elements. So that’s all fine if you can do it, but here we are talking about a very simple display at first that they’d achieved. But then the group got ambitious and said that they wanted to actually make a picture forming display and they persuaded the management that they could do this, but were given only I think two or three years to do it. And after the three years they had made some displays that worked and they’d even made a mixture of material that worked at room temperature based on a mixture of Schiff’s bases. What they hadn’t yet made was a stable material, but it did work for a few weeks. On the other hand, the display itself, though they didn’t advertise this, didn’t work for much longer anyway because of the impurities that they added to make it work. So although it was an
interesting invention it wasn’t a solution to the problems of a flat panel display, it was a first step. The team then tried to get the development department to support them in an endeavour to get extra funding for the work and to do more complex things, and the development department were not keen and the reason why they weren’t keen was because they had had a considerable success earlier in making a colour display for television, and this was a cathode ray tube that had a device inside it, a mask inside it which ensured that electron beams from three cathodes sending out electrons fell on different coloured areas of phosphor and a phosphor emits light when an electron beam fell on it. And because of the construction of the shadow mask tube you could ensure that you saw a colour picture. And this was in the early 1960s and was the basis for colour television throughout the world. As a result, the Radio Corporation of America, RCA, had a monopoly throughout the world in colour television and the world was asking for more and more colour television sets. So RCA was licensing their technology, which is obviously covered by a number of patents, to manufacturers all round the world, in England for example, the English Electric Valve Company at Chelmsford had a monopoly and they had a factory that was put up that was making shadow mask tubes. And that was repeated all over the world in all of the companies. And naturally the licence fees were bringing in a large sum of money, and if we can cast our mind back to an earlier talk, we mentioned that John Stonehouse was affected that the licence fees from the shadow mask tube were costing the country more than Concorde was. And that was true and it was a large sum of money coming in. The development department that had been instrumental in developing the shadow mask tube so it could be made and made reasonably cheaply, said why should we be interested in liquid crystals, we’ve got a world monopoly in this tube, it’s a marvellous tube, we might be able to improve it slightly, but it’s working very well and is bringing in so much money for the company, why do we want to help to develop a rival to our own product. Well, the answer I would have given them if they’d asked me, but of course they didn’t, was to say well if you don’t, somebody else will. [19:30] But they didn’t, nobody asked them that, they didn’t get that answer, so in 1972 the RCA work stopped, they gave up. Now if they’d just given up negatively and sort of left the field, that would have been one thing. But they didn’t, they left an inheritance and the inheritance was the leader of the team George Heilmeier. George Heilmeier had invented this dynamic scattering device, was anxious it should be made throughout the world, and RCA had persuaded and licensed a number of Japanese companies to start making numeric displays and digital watches based on that technology. That was a poor decision which actually upset a lot of people later on, because both the material and the device itself had fundamental faults in them which meant you could never, never ever make them work over a long period. We were unkind and said that it was three weeks, actually it was more like
three to six months, but even so, the companies in Japan were beginning to market these inadequate devices. George Heilmeier had left RCA in 1970, I believe, around then, and had taken a very senior job in the Department of Defense where he was responsible in a sense for a parallel organisation to CVD due to give all of the contracts on electronic materials and devices. He had this position where it was up to him to decide which contracts were going to be let. Now, an unkind person would say that he thought everything that was necessary in liquid crystals had already been invented by him, so nothing else was needed. That would be unkind, but he certainly took the view that in defence there was no need for a flat panel display. We know he said this because he actually published a paper at the Device Research – no – the Solid State Devices Conference had a session on displays and he gave a keynote speech in which he said we will not support research in this field because we cannot conceive a scenario where our pilot loses an air battle because he has cathode ray tubes in his displays and the enemy has flat panels. And he said that. Now, of course now we would say that was ridiculous, but he did go on record and said that. Now, you have to cast your mind back to the financing situation in America, as in the UK, where it was heavily dependent on defence funding. So if the man responsible for electronic contracts takes that view, it’s very likely that people would become discouraged. He didn’t have full say on the funding because there were people in the Navy and Air Force who might be prepared to place contracts, but they would never have dared to have gone very much against what was said. [23:30] Now there was an alternative, which was essentially industry doing things on their own, and industry is very much a copycat organisation that it’s rare that people will take too much departure from the party line. You get a bandwagon developing and people will jump on the bandwagon but it’s not many people want to start the bandwagon. And in this field they had seen RCA start a bandwagon and then give it up. So it wasn’t actually a climate which people would follow and then there were very influential people in Bell Telephone Labs. Now Bell Telephone Labs certainly was a role model and people did tend to watch what they were doing and would often copy it and there were people and a lot of the chips and later circuitry came from people had worked at Bell Lab and then had left it to set up their own companies in Silicon Valley, so you can trace history that way. So Bell Labs was very much a focal point. And Head of Devices, device research and development there, was a man called Eugene Gordon and Gene also joined in the fray and he also published an article in the IEEE journals saying that he was unconvinced about the need for flat panel display research because we had already an excellent display of electronic information in the shadow mask tube and he couldn’t see any need for an improvement. Now that was pretty short-sighted actually because it wasn’t allowing for the changes in voltage and size of electronics, because the chip was coming
along. But as a result you had these two people, both in very influential positions, who were saying, we don’t think that display research is necessary or advisable. And as a result the people who were keen on display research, and there were a large number in the States who didn’t agree with this, but they didn’t have the funding available to them and at the same time we were beginning to develop what was happening. And then, and I can actually testify to that climate, because later on… [pause]. I’ll be there in a minute, don’t worry.

Got a whole bunch of questions I want to ask you about this as well once we’ve…

In 1977 I was asked to come to the States and give them an answer and really give the keynote speech at the Solid State Devices Research Conference on displays, and my talk was given, the title ‘A Constructive Philosophy on Display Research’. You will get the pun. And I basically said that they’d chosen the wrong people to give their keynote speeches, that asking people to talk who’d got a negative view on the subject was a bit like the feminists asking a male chauvinist to address them, which didn’t go down too well, but at least it was there, and that was the paper I gave. And I gave this paper to people who wanted it, but it shows I’m saying this not because I had a monopoly in looking forward, because it shows what the climate was like in the States at the time, that they actually couldn’t find anybody with any reputation to actually stand up for flat panels. Meanwhile, in the rest of the world of course, they didn’t have these limitations of lack of funding or essentially of lack of foresight, and they were beginning to develop the things that were necessary. [28:30] And the two things that were necessary - and we’ll get back to George Gray in a minute, which is where we left this as a digression - were the twisted nematic effect which had been invented by Schadt and Helfrich at Hoffmann-LaRoche –and that’s in itself interesting because Helfrich had actually worked in the RCA group before he’d left and he had in fact, as he admitted later on, come up with this invention but he couldn’t get Heilmeier or anyone else to listen to him, so he’d then left there and gone off to Switzerland where Schadt did listen to him and perfected his idea and they came up with this twisted nematic effect. Now the virtue of the twisted nematic effect was that you didn’t need impurities, so it didn’t have the seeds of death in it. But of course if you made it with the liquid crystals [29:30] that they had available, it still had the seeds of death because the liquid crystal would die. But the combination of the twisted nematic effect with a stable liquid crystal really was the answer. So we could say to George Gray what we want him to do was to make a stable liquid crystal. And we had an advantage over other people because of our defence background, because defence insists that its equipment must be reliable. It must be reliable because often it’s not being used, it’s in store, and they cannot have
equipment that’s in store and dying, they have to be sure that when they get it out, even though they haven’t needed to use it for years and years, when they get it out it will work. And we had all of the facilities at Malvern for testing devices over long periods of time, at different temperatures, at different environments - we could change humidity - we could do all kinds of tests on the material. And we knew about this and how to do it. So we could say to the people in Hull, this is what you need to do and we will test what you’re making. There then proceeded two years of frustration where they and other people, I mean we had no monopoly in seeing the need here. Chemical departments in most companies were now interested in liquid crystals and they were trying different compositions and history shows about six different types of organic compound were being tried. And they failed in different ways. Some failed because it was very difficult to make the device without some water vapour or oxygen getting in. Others died because they couldn’t stand an electric field. Others died because they couldn’t stand light, they were photochemically unstable. So it was getting to be a very confusing picture, and then George Gray had a moment of genius – well, it may not have been a moment – but a period of genius where he looked at all these different things and thought there’s something they’ve all got in common isn’t there, they all have a chemical bond that joins two phenyl rings, an organic phenyl ring – generally there are other rings as we’ll come to maybe later on – but they all have a bond. Why don’t we join two phenyl rings together and make a biphenyl without a bond of different chemicals at the middle. And the reason why you don’t do that is because the temperature at which it’s nematic shoots up. So it wouldn’t work, you wouldn’t be able to get a room temperature stable crystal that way. But, if I add a cyano group on one of the ends I know that brings down the temperature at which the thing works, so why don’t I make a cyanobiphenyl and see at what temperature that works and if it forms a liquid crystal. Well he tried it, or at least he was in the States when actually his student managed to complete the reaction that George had asked him to do and when he got back he found we’ve made it, we’ve made a cyanobiphenyl, and it is a liquid crystal. What of course we don’t know yet is if it's stable. So they sent it to us and we exposed it to the atmosphere. And we showed that after a week, although it had changed it still had liquid crystal form, it hadn’t changed much, whereas if we took a Schiff’s base or one of the other things and just exposed it and tried it, in a few hours it would be useless. So it showed all the measure of stability and when we used it properly and put it in the cell it was absolutely stable. But it wasn’t what we wanted, yet.

Why?
Because it didn’t work over the temperature range. Now by now we knew the temperature range that people were asking for because they’d made watches and numeric displays for instruments and things and there was a market developing and it was very nervous because they knew the devices didn’t last for long enough and they couldn’t use the materials that RCA had developed, first because they weren’t stable and secondly because they did need heating and nobody wanted to, well you couldn’t heat the display in a watch. So there was a real need arising. And the temperature range over which they wanted them to work was 0 to 60°C. Well actually, they wanted -5 to 60°C. You can argue why anybody should want something that they’re going to wear on a watch for less than zero, but they did have an explanation that watches are sold by jewellers, jewellers put their products in the windows of shops and people come and look at them and you cannot heat the window of a shop, so the window of the shop might well get below zero and you want the devices still to be working, so you want them to actually cover this range. So we had a specification, they told us the voltage that they wanted them to work on, which was something below six volts, and the various things: they’ve got to be colourless. And we knew we couldn’t do it. Right. [35:55] And the one thing we couldn’t do was the temperature range. But we did know a bit about mixtures of materials from what we had done with solid crystals and we knew that if you put two materials together that very often you had what was called a eutectic whose properties were apparent at lower temperature than either of the two constituent materials. You can make a eutectic from two solids and its melting point will be way below the melting point of the two different materials. So we knew that maybe a mixture would do it, and George and his team hadn’t just made one cyanobiphenyl, they had made a range of, a family which had different alkyls and alkoxy in them, so we had a range of perhaps ten to twelve materials that we could choose and we had a strong feeling that if we had a mixture of these then it would give us what we wanted. But how the hell do you sort of design a mixture from ten or twelve different materials that has this range? You don’t know which ones you’re going to use or how much you’re going to use of each one and you can easily miss the whole thing. Well then one of the people in our group, Peter Raynes, who has been mentioned I think before, had an idea, that if you knew the thermodynamic properties of any particular material you ought to be able to predict approximately what would happen when you mixed it with another material. And he showed by an experiment on two of the materials that this was indeed true. It didn’t give you exactly the properties for the mixture but it did show you what could happen and he came up with a formula which could be applied to any mixture. And this was so good that he showed that the materials that George had made could never give you the right specification that was necessary. That wasn’t great news, but then he said, but if you make another material, which is a terphenyl, which
has three rings, then adding one of those, that family of terphenyls to three materials from the biphenyl group will give you this mixture. And he said this and he proved this actually without us having made a terphenyl properly. Interesting, he predicted this, that we could do it. Now…

*On what basis?*

Mm?

*On what basis?*

On the prediction of the family and the way the thermodynamic properties would vary as a pattern, and they could make a small quantity of these to show this. [39:30] Well, one of the things we had to consider was what would we do with the results of the Hull group, because the Hull group was a group of chemists, I mean they could make gram quantities of the material, but we had our own group of companies that were interested in making displays, I mean people like Plessey and STL and Philips, they wanted to make displays themselves. I mean they had the research teams, but they had the production teams who were interested in making displays and selling them. And we had other people who weren’t as closely associated with us like Racal and Rank who also wanted to do this. So we could see that there was a market for the materials, but who was going to make them, because Hull wasn’t going to be able to supply kilogram quantities to people. So I then turned to a company called BDH, which was down in Poole. I didn’t have the problem of supply earlier when we had started production essentially of the microwave oscillator. You remember we dealt with that and said we were making miniature radars, and of course there we had exactly the same problem, that the more successful we were in the devices we were producing for small radar sets that had many applications the more people needed the gallium arsenide and who was going to make it, the research labs weren’t going to make it, so we had to find a source of the material from which people could make devices. And I asked the development director at BDH, a company in Poole, whether they would be interested in doing this and he, with the name of Ben Sturgeon, said well, yes he supposed they could but they’d no experience of dealing with these semiconductors and things, it wasn’t something they really wanted to do, but they could have a try and see how they got on. And they had managed and made reasonably pure material following the prescriptions that we gave them from our different contractors, Plessey in particular and STL, so they had a small business going in making gallium arsenide. And I asked Ben to come and see me at Malvern and explained what we were doing
and said would he be interested in doing this. And he looked at me and said, ‘Cyril, do you know, this is the first thing you’ve asked me to do that I know anything about’. I said, ‘You do?’ He said, ‘Yes, I’m an organic chemist’. I said, ‘Oh, are you Ben? I didn’t know that’. He said, ‘Yes’ he said, ‘I’ve only made the gallium arsenide and indium phosphide for you as a favour’. He said, ‘We’ve never really known’ he said, ‘most of our business is organic chemistry and this we do understand’. So he said, ‘Yes, we’d be only too pleased to start it’. So they started doing it and within five years it was their biggest product. In five years, to go from zero to being the world supplier and it was responsible for half of their profits that year. And Ben’s contribution is actually recognised now. Ben never could get the recognition that he deserved. The other people as we’ll talk to later got medals and things from academic and international institutions and became Fellows of the Royal Society and all kinds of things. But Ben never quite got the thing, but then after he had died he did get recognition from the Society for Information Display and there’s an award in his honour. And he was unsung, but on the other hand, it wouldn’t have happened without him because it wasn’t easy to make these liquids. Nobody had ever made liquids to that degree of purity. People were used to pure solids when you make semiconductors – silicon, germanium and the others – you know you, I mean one part in a million isn’t anywhere near good enough, you have to get down nearly… ten parts per billion is nearer. And you do that and don’t think about it and in fact people have made solids much purer than that. But liquids are more difficult to purify in that way, and yet we realised after a time that we did need to get down to this, better than a part in a million, and to do it in quantity. And Ben showed how it was to be done. In fact the terphenyl was a fiendishly difficult thing to make in quantity. Though Peter Raynes had shown that it was going to be necessary, it was Ben’s genius in production and knowledge of organic chemistry that meant that BDH were able to make it. So we made this mixture called…

**What sort of chap was Ben anyway?**

Mm?

**What sort of chap was Ben?**

He was a bachelor, he played chess, smoked a pipe and was quiet but forceful. His company, BDH, was later taken over by Merck, which raised some political problems in MoD because we had licensed them.
Merck, sorry?

M-E-R-C-K. Chemicals. The biggest independent chemical company, probably in the world now. I mean it’s still privately owned by the Merck family, but it’s very big. It was quite big in liquid crystals then, but they were making their own materials and I suspect that one of the reasons they took over BDH and bought it was because they could see the power of the liquid crystal that we were opening up to them.

What sort of interaction did you actually have with Ben at BDH over this? Was it just a case of telling him to go away and solve this problem or was there sort of inter…

Oh no, there was constant – it was a consortium – there were constant discussions between the various people involved; obviously our group, Hull University. STL were heavily involved as well in making devices as well, they wanted to do it. And I don’t think Plessey were involved in liquid crystals, Plessey were doing other things in displays, they did a large number of other things. I don’t think they ever got really involved in liquid crystals. But there was close interaction, particularly between us, Hull and BDH.

What sort of interaction?

Constant visits and constant pooling of information and trying things and none of it worked very smoothly, it all took a long time. Now you can look back and see the way you went, but it did take quite some time. [47:50] And at the same time we were collaborating. It wasn’t long before Merck took over. I’m trying to remember the actual timing. But at some stage I first of all realised that we were on to something that was commercially important and I immediately had a freeze on any mention of the materials that we were using. The mixture was called E7 and that was how it was sold, and people did not know what was in it and nobody was allowed to publish anything that mentioned what was in it. We had to patent it, but we knew the patent wouldn’t be coming out for some time and we could start selling it. And I took over the licensing. I’d had enough of a problem with the Admiralty licensing people, in fact the people at MoD – well, it wasn’t MoD then, it was Ministry of Aviation – were much better, much more professional, but they were happy to leave it to me and I decided that we would license two companies, not one, even though I did trust BDH and as it was, Merck, I wanted to ensure there was some
competition. So we said we would license Hoffmann-LaRoche as well. Hoffmann-LaRoche were the people who had done the twisted nematic display, so they were very interested too in having rights to this material. And these were the only people we licensed and I tried to get device contracts in Germany and to actually get a return to us for any use of the liquid crystal that had been made, but I was told that that was not possible by German law, that once a material was on the market it could be used, you couldn’t have a double licence for it. So as a result I knew that if we simply took a normal return on the actual material, that the amount of money we would get in would not be large, because it never is. So I actually said that we wanted a licence fee of fifteen per cent. This was later said by CBI to be usurious or something, that it was ridiculous, because it should have been two or three per cent, and the view I took was well, this is a new material going on the market, nobody knows what the material is except – how much it costs – except the manufacturers, they can just add the extra licence fee on to the cost of the device and nobody’s going to know because they’re going to multiply how much their spending by some factor and essentially they’re just going to sell something that’s new. So, what’s wrong with that amount of money? I think it was Merck by now that was coming in, but they were talking through BDH and they said it’s too high, we’ll give you twelve and a half per cent. But then Hoffmann-LaRoche came in and said all right, we’ll give you fifteen per cent. So I said to Merck-BDH, there you are, take it or leave it, so they said all right. And afterwards, not a word was said about it. The licence fees were set and for twenty years the royalties came in to the Ministry of Defence, though later it wasn’t Ministry of Defence, it was DERA and then QinetiQ that came in.

[51:50]

How did people within the Ministry, your organisation at Malvern, actually take to the idea of this fifteen per cent figure?

They were thrilled. Yeah, they were thrilled. I mean they’d never had anything sort of coming in that was so clearly in demand. The only other thing you could compare was carbon fibre, which people had been developing at Farnborough and they did not handle that very well, they got very little return on their inventions and they were ahead and I don’t think they fully understood how to exploit it in the right way, because you know how carbon fibre is used now and you can trace that back if you do your history to the work that was done at Farnborough. And the people got their academic rewards out of it, curiously enough, and people appreciated what was happening but nobody sort of pointed a finger at them and said why didn’t the government make money out
of this, I mean it’s used in tennis racquets and almost everything else. But, why? Anyway, not my business.

*Why did you think you’d get away with fifteen per cent? On this stuff in particular?*

I actually was prepared to negotiate. I knew that I wasn’t going to accept three per cent. I was working roughly on the basis that I want three per cent, two or three per cent on the value of a device that is using this material, because I’m not happy with the device people taking all the benefits of the material. But if I now work on the basis of the device is going to be in order of magnitude more expensive than the material, then if I had a three per cent return on the device, that’s equivalent to a thirty per cent mark-up on the material. Nobody’s going to agree to a thirty per cent, so why don’t I divide by a factor of two and get fifteen per cent. So the fifteen per cent was thrown in there as – and it can’t have been far off what people were prepared to do because Hoffmann-LaRoche did not argue in the least, they knew they had something new, they wanted to sell their devices. They were, together with Brown, Boveri, a very big engineering firm in Switzerland and they could see they had a market there. We really had them in a vice because the need had been created for flat panels for numerics and watches and they knew that the materials they were using were going to come back and bite them before long. And you’ll see, some of this is done in history, there’s a man called Kawasaki I think his name is, who did a history of what it was like in Japan at the time and they were completely frustrated, particularly the people who’d made the decisions to go into production. And they could see that although everything they did was an improvement, they could never get the devices to the stage where they were going to live for long enough to be a satisfactory component for them. So they were anxious to have something and of course they were scouring the world for something, and there was no competition, there was nobody doing anything. This was something that lasted for the full twenty years of the patent and still is used. It’s not quite used as much, but sometimes it’s a component of displays and there you are, it was ’72 – what have we got, forty years. It’s not bad. So yes, we had them in a position where they needed the material. The problem wasn’t actually the argument over the licence fee, it was can you make enough for us, because we need it in quantity and the pressure was on Ben because materials, they’d never produced it, they were used to producing grams of these pure materials for academics and for the research labs and suddenly it was a production material so Ben had to work out ways of increasing his production a hundredfold. I’ve got pictures of the increase in the scale of the material, but it shot up because success bred success as they were able to show that they now had a stable material and device for
watches and for numerics, particularly for watches, you could see them in all the jewellers’ shops. In fact, one of the great things about the group was the spirit within the group where they were saying that well, took my wife out shopping and pointed to the digital watches in the shop and she said, ‘Well what’s in that?’ ‘My material’s in that.’ ‘Your material?’ ‘Yeah. That wouldn’t be there without me.’ And they could never have done that before. It was a totally different spirit that came over the group, and of course it was reflected in the way in which they thought because I didn’t always get into coffee time, but when I did get into coffee time I’d hear somebody saying that, oh they’d discovered a new thing in their liquid crystal experiments. And immediately the senior people would say, what are you doing about patenting it? Now, if you’d been an academic group they would say, oh were you thinking of publishing it. That wasn’t the first question, the first thing was, are you patenting it? And before long our group was, which was probably about fifteen people, was producing half of the patents coming out from the Ministry, the whole Ministry, and that continued for many years, that the spirit of the group was to invent applications and before long, and I’m jumping ahead a bit here, we actually had patents on devices as well as materials. So we’ll come to that later on, but – and that’s what started bringing in more money.

_How much was this actually worth to MoD, the country, in terms of patent for everything?_

The patents on materials brought in a few millions of pounds, probably five millions. The patents later on devices brought in over a hundred million pounds. There have only been I think five inventions in the Civil Service that have brought in more than a hundred million pounds and this was one of them. I did once know them as, oh I forget, but I could probably remember, but there are only five in the whole history of the Civil Service that ever brought those in. So we were popular.

[59:20]

_I’m interested in E7, the idea of not letting anybody know what’s in the material, not letting people publish on it. How concerned were you about the secrecy of your discovery?_

Well, we were very concerned because we knew that other people would jump on to it. I mean it’s very difficult to keep some research results quiet because if you’ve got somebody working there he can leave and go elsewhere, and there was very little know-how involved in this. Once you knew what the material was you could do it. Actually, this was shown later on where the Merck people, when we got tied up with Merck and they knew we had these patents, were
charging, they came up with their own material that was also a biphenyl, but was a phenylcyclohexane, which essentially is a distorted phenyl ring and it actually was very irritating to me because you’ve got to remember that I had given up chemistry at fourteen and here was I running a group which essentially was based on organic chemistry, of which I knew damn all, I mean I’d have to pick it up and think about it. Now the others in the group had all done chemistry at least to A level and they knew about these things, and when I heard that PCH had suddenly come on the market with some advantages, not complete advantages over the biphenyls, but it was an interesting additive so they could get a patent on it and could add it to some of their own mixtures. I said, ‘What’s all this about another phenyl ring? I didn’t know there was another phenyl ring’. They said, ‘Well of course there’s another phenyl ring’. I said, ‘Why didn’t anyone ever tell me?’ They said, ‘Well we thought you’d know’. ‘How would I know?’ I said, ‘Are there any other of these rings?’ They said, ‘Oh yes, there’s another one, there’s the bicyclooctane’. I said, ‘Well we’d better have a look at bicyclooctanes then hadn’t we and see whether we need to patent them’. But it was a very unstable situation. But the need for secrecy was pretty obvious, that people would have copied. And what is more, they did. It wasn’t straightforward. Now, this was partly in the hands of the patents branch now in ensuring that we were getting the royalties on our material and we knew that there were going to be problems in China and in Russia. What we hadn’t anticipated was we’d get problems in America. But once the material started coming out there was pressure. Beckman Instruments publicised that they were going to make a material, and it turned out when we looked at it that it was a biphenyl. And I rang the President, who I happened to know. He was a semiconductor person and I said, ‘You know you’re marketing this material?’ He said, ‘No, I didn’t’. I said, ‘Well, you’ll find it’s advertised, that you’re marketing this material and it’s clearly a material that’s based on our patents and we’ve never licensed it’. He said, ‘Oh, will you license us?’ I said, ‘No, we can’t because we’ve given rights to exclusive licences for the next two years to Merck and Hoffmann-LaRoche’. He said, ‘Oh’ he said, ‘So what do you want to do?’ I said, ‘Well, I’ll happily arrange that they can supply you with material that you can then sell on, but we can’t allow a situation where you’re doing it independently’. He said, ‘I’ll get it stopped’. He said, ‘We’re not going to go into this kind of business, it’s not worth it to us’. He said, ‘We’ll work with your suppliers’. So that was done. With China we, actually they were selling it through Hong Kong and fortunately Merck were quite strong in Hong Kong and they threatened legal action, but what they couldn’t do was stop them making it in China and making devices in China, which they then exported. And it was very difficult for us to stop that happening. Fortunately the Chinese never quite got the material to the perfection that BDH and Hoffmann-LaRoche did, so they found they
couldn’t really sell the things outside China, so we didn’t bother. Russia never seemed to bother, they just bought the material, but what did happen was every few months I would get somebody from a Japanese company coming in asking me for a licence. I mean they tried the patents people in London, trying to get round it, but they said no, there’s no way they can do it, they’ve got to get permission from me because I was solely responsible. I was getting quite senior now, so it wasn’t that strange and they would come to me and beg and I remember a man from Chisso, a very big Japanese company, saying that my reputation’s at stake here, I cannot go back and say to my family that I have failed in this job that has been given me by the company. I said, ‘Well, there’s a perfectly good explanation you can give them’. He said, ‘What’s that?’ I said, ‘Well the man in charge is completely unreasonable, he does not accept logic, he is prejudiced, he is biased’. He said, ‘What, you, you mean?’ I said, ‘Yes, yes’. He said, ‘You don’t mind my going back and saying that?’ I said, ‘No, no, I’ll give you a letter if you like, to actually say’. ‘No, no, that’s not necessary. But if I can say that you are definitely prejudiced against Japan and biased, that is sufficient’. I said, ‘Yes, yes, by all means’. He said, ‘Oh thank you very much’. So they went back and my name was probably dirt in Japan. Made no difference. I mean just… but in fact Chisso themselves realised that what they could do is come to an agreement, mostly with BDH. No, I don’t, kind of lost touch. I think Hoffmann-LaRoche looked on it more as a badge that they could provide it. They never produced more than ten per cent of the world supplies. BDH always were well to the fore and particularly when Merck took them over, Merck were taking it very seriously, and still do, and our relationships with Merck were excellent in fact.

*I’ll pop you on pause a second.*

[end of Track 18]
Why were you so keen to keep the licences to just those two companies?

Because I knew from my experience with the magnetic susceptibility meter that you shouldn’t rely on one company, no matter how trusting you were, that organisations change. So I had determined that I would never put my trust in one company, but I knew that we could only persuade them to do this thing if they knew that it was going to be restricted. So it was just a question how restricted and I thought that this essentially is either a two or three company and there were two companies. We were approached by others like ICI and other people who all wanted to get in on it. I knew we were going to license BDH, it was logical to license Hoffmann-LaRoche because we wanted an insight on the devices anyway, doing that, so that was all sensible. Did we have anyone else? There was no strong case for anyone else, so we arrived at the number two. But I think that originally we only said it was going to be for two years or something, but it was renewable.

I’d like to talk a little bit about the state of the work in America in comparison. I was wondering how much of the story you’ve outlined to me you were actually aware of back at the time in about 1970, say.

We knew about the lack of success in America, there were always conferences on liquid crystals. People that were interested in liquid crystals, there were academic conferences where people would talk about the properties of liquid crystals. Nobody worried in academic circles about having to heat materials, but there were people in America who were eager to fasten on the lapses of RCA. IBM were very conscious. One of the materials... I think there were five families and probably two of those came from industrial circles. There was a lot of activity in the States but it was in the research labs of industry and academic circles rather than in the development departments, because basically it wasn’t successful. If any of them had come up with a successful material they certainly would have done it. There was... RCA had created this need and then they'd abandoned it halfway, so there were people who had almost half completed devices on the production lines wanting to do things. It fitted a number of things that people wanted. There was the consumer market for watch displays, but there was also a need for numeric displays, the displays that people were using. People were beginning to use LEDs as assemblies and things, but it got quite cumbersome and you can’t do a complex message with
LEDs very easily. You can do a seven bar for numbers, you get seven bars and they will give you any number from zero to nine. If you want to really do a message you’ve got to have thirty-six – thirty-five – picture elements in each box to cover the whole alphabet. It’s a seven by five picture that you get to do this. You can do more complex things, but you can recognise seven by fives will cover the whole alphabet. But that’s thirty-five elements for each thing so it gets quite complicated for an LED. The kind of things that people were doing, they were doing fluorescent displays and also neon lamps, they had a complex neon lamp. All of them they were higher voltage, none of them were very satisfactory.

[04:50]
*I was interested in the sort of hostility to the idea in some circles in the United States and I was wondering what the reception was like to the idea of liquid crystal displays in Britain in comparison?*

Oh, Britain was okay. There was, America was hostile because they didn’t like the idea of things coming in from outside. When I gave presentations, which I did in the States on this new family of crystals, they immediately started attacking me on the grounds, first of all of toxicity, that these things were carcinogenic because there were some reasons for saying that and I said, oh we’ve done the tests with fruit flies, and we had in fact – and this was partly BDH, but certainly partly me as we – we had almost designed with the Department of Health, the tests on the material as to whether it was safe or not and we had supervised experiments which had been done with this company, which later on had a lot of problems with animal health people, of actually feeding biphenyls to rats. And we’d shown that you almost could feed them their own weight in biphenyl before it had any effect at all and we designed with the Department of Health the kind of level of tests for it being safe. And they were very grateful for the work we were doing and we could point this, and then the Americans were complaining on the grounds this material was so non-reactive that it would go into the soil and pollute the soil. And I said, if it’s not a, if it’s not a filter it must be a photocell. They said, what do you mean? I said, if we’d said they were toxic you would have said we can’t have them, now because they’re not toxic you’re saying we can’t get rid of them. And in the end they just realised, they just, I said if it had been American then it would have been all right wouldn’t it? And they sort of retreated. But that’s what it was, they didn’t like the idea that something had been invented outside the United States, particularly when it had – I’d better be careful of my language – it had started in the United States, I mean it was ridiculous what they had done. And we will come to other things which again showed that
America had been so close but then because of, I suppose it was management decisions, they had missed the boat and they weren’t happy with that. I suppose I can’t blame them.

*Did you actually know George Heilmeier?*

Oh yes, oh yes.

*What sort of chap was he?*

He was fine, he was fine, there was no problem with him, he was very clever. But he, I imagine he was very irritated with the attitude of RCA, I would have been and the group certainly was, but… He was probably a bit too single-minded. Certainly I would have been very upset with Helfrich, with what had happened with Helfrich, because Helfrich was a theoretical physicist and he’d observed what had happened in the group with the devices that are made and came up with this idea and he said well, he did show it to Heilmeier and the other people and most of them thought it was okay but Heilmeier objected because it used two sheets of polaroid, which meant the actual transmission was only like ten per cent. It may have been a little bit more than that, theoretically it’s fifty per cent, but in practice it’s not as high as that. And he didn’t think that people would actually want to use the material with polaroid in it. But the answer was if it’s the only thing that works, I mean if it works you just put up more light behind it so it works. But he stopped Helfrich and Helfrich didn’t push it, because in his own words he said he was not paid to invent devices, he was paid to explain the physics to those who did. Now, that’s a compartmentalisation which I would find very difficult to accept in a member of my teams, that you don’t have people whose job it is just to do one part of the thing working with the others. But it is a fact that he went – he left RCA in September of one year, worked with Schadt at Hoffmann-LaRoche who he knew previously from both working in Canada together, during October and November, and they published the paper in December and patented it just before they published it. Now, that can’t happen. I mean you don’t do that, it doesn’t work that way that you leave a company and you immediately invent the things, and it’s in the literature, this isn’t something I’ve made up. It’s in the literature that he admitted that it wasn’t new. The strange thing is that RCA never objected to the patent and that must have brought in millions and millions of pounds to Hoffmann-LaRoche, because it was the basis of all liquid crystal displays, and it was a device so it could actually have a higher royalty than I could ever charge on the material.
The big thing I’m interested in as well is the team, the group you’ve mentioned a few different times in passing, and I was wondering if you could give me an idea of, you know, what’s the structure of this group, to begin with?

Well remember, I had an individual merit position, so I had no sort of administrative group. The only group I had was the people who wanted to come and work with me and the facilities that I developed. There was a superintendent of the division who was probably junior in rank to me, but he was responsible for the people, but in every case I never had any problem with the division leaders or the group leaders, they all sort of basically gave me my head. Everything seemed to be fine and because things were working people wanted to be associated with what I was doing. I didn’t control them. I advised them, I was responsible for organisation of the projects but what they did themselves, they would talk to me about it and would go away and do things. Not always, I will say, later on there was one person who deliberately disobeyed what I suggested he ought to do. This was because the work was being successful and the liquid crystal companies wanted us to be expanded, they wanted us to do more, but I couldn’t do more because we had a headcount restriction that we couldn’t recruit more civil servants. We could take on visiting scientists, but they couldn’t do this, and Merck asked if I would be willing to take on a BDH fellow. They would pay all his expenses, his salary, he’d be on their staff but he’d be seconded to work with me. And the Establishment said fine, he’ll have to be security cleared and everything in exactly the same way, but then yes, he’ll be a visiting fellow. So, I recruited one for three years and then he wanted to join us, so he then changed and when a vacancy became available he applied for it and was recruited. He was replaced by somebody else. I forget how many we got through actually, we must have got through at least two, maybe three. And the third one wouldn’t work on materials, he wanted to work on devices. I mean he was recruited to work on materials and I pointed out to him that Merck had put him with us and was paying his salary. He was a Merck person, he wasn’t supposed to work on devices, would he kindly work on materials. And he said yes but then took no notice of me, and then went and invented a device that brought in tens of millions of pounds, if not a hundred million, yeah.

What was the material?

Oh, it was a device he made, yeah. He didn’t work on materials at all, he wouldn’t, I mean, well I don’t suppose Merck was thrilled, but on the other hand, they benefited from the sale of devices
that used their materials in it. It still used Merck materials in it, or BDH materials, but it was a
device that he’d invented, which we’ll come to later. You asked about people, well that was an
example that, what could I do? Could I go and sort of stand over him? The people did more or
less what they wanted. I knew what they were doing, obviously, but… and I had some say quite
often in ideas as to what was going to work, I’ve got a string of patents in various things and
devices and I mean it would… there were no boundaries. And the other interesting thing is that
people from other groups wanted to come and work with us and sort of take over our philosophy
and before long it was spreading, I mean we started off, remember, as a defence laboratory,
making things for better radar sets and flat panel displays for military applications and there were
some contracts going out for specific devices that were made and some of them were made for
defence equipment, STL made some for defence equipment. The trouble was there that the
requirements that were put on the devices meant that the devices themselves were quite
expensive, so they weren’t going to go in. But then there were other companies coming in that
wanted to make watch displays and numeric displays and they were being partly funded by. I
suppose it was the Department for Industry, it might have been the Department of Trade and
Industry by then, and there was another group in Malvern that was working on air traffic control
that wasn’t quite defence but it wasn’t far off defence, and they were in Malvern and they were
funded by the Department of Industry and then I was asked if I would take responsibility for that
group as well. That was a small group, that was three or four people, and they wanted me to sort
of really look after them, they’d felt they were being neglected in their area, they were a side
issue to another thing and their group head, who I knew very well, wanted me to really take
responsibility for them and the division leader there was also quite willing to do this. So I
inherited the responsibility for air traffic control. And that was fine, it worked very well, they all
sort of worked together as a bigger group and would talk together, there were no problems. But
they knew their responsibility was a different one and they would be, they might be using
different displays or might not, but they were part of the total team. [18:35] And then the
Ministry of – I got to know Kenneth Baker quite well and the Chief Scientist that they had there,
John Noyes, and they asked if I would look after the civil programme as well, they wanted to
develop a civil programme so would I develop the civil programme in the UK, which involved
the people wanting to make watch displays and numeric displays which were partly funded. So
the whole thing in the UK became very coherent and in fact part of the time I think my salary was
half paid by the Department of Trade or Industry. I never enquired and MoD came to some
agreement with Department of Industry that I was doing these things for them so there should be
some financial arrangement and I think they arranged that I would be paid half by each of them.
It made no difference to my salary, it still came in. But I was doing quite well in my reputation here, I was quite popular in the system. They could see it all working and they had no reason to object to it.

_I'm interested you mentioned a little while ago that your position as a special merit promotion in this organisation was to advise rather than to control – could you explain the difference between those two things as you saw them?_

Oh…

_Perhaps with examples._

Yeah. It does become a bit blurred when you get the larger group, but essentially individual merit is supposed to be free from administrative responsibilities, that’s the thing, it’s the freedom from administrative responsibilities, that nobody can ask you to do something knowing that with power that there are certain reporting requirements and things that might be restrictive. But it becomes a bit blurred because if you’re responsible, if you’re actually running the programme for somebody there are certain requirements in personnel development of course that it got really quite confusing. You see, for instance, with the scientists, they would be interested in promotion, in going up the ladder in there to become Senior Scientific Officers and Principal Scientific Officers and obviously I had to think of this and I would be making recommendations. At the same time later on I was responsible for all of the Principal Scientific Officer promotions because I was running the Principal Scientific Officer boards. It was very convenient to have somebody like me around you see, because in principle I was independent but I was actually responsible for the PSO boards and also I had got well up into the individual merit thing. I don’t know quite when this was, but since I moved on in ’83 I think it must have been the late seventies I was promoted to Chief Scientific Officer. Now that was very unusual to be at that rank in the Civil Service, it’s equivalent to a brigadier general or something, it became ridiculous in the hierarchy, but it did mean I was the same level as a superintendent of not the biggest establishments, but superintendents of quite a big establishment and yet I had no administrative responsibility in theory. So I was an individual merit at the top level. At one stage I was the only one in the Civil Service who was this. Later on a mathematician was equivalent to me, but only two of us in the whole Civil Service you see, so it was an interesting position. And this meant I was actually responsible for putting other people up for individual merit promotions because obviously I was
supposed to know what was required in this, so before long I actually did have individual merit people working for me. Well not for me, with me, I should say. And it was a bit unusual but it did work. In principle anybody could have said that they wanted to go and do their own thing, that would have been fine. And in fact we didn’t find that was happening, we found it the other way round, that people wanted to come in, the theoreticians wanted to come in and work with us on liquid crystals now, they’d never worked on liquid crystals. But they wanted to come in and work and in fact one of them did say he wanted to come and join the group and I said no way, no, no you can’t, you’re in the theoretical physics group, I’m not in the business of poaching people from other groups. I’m happy for you to work with the team, there’s no restriction, you can talk to anyone you like, I don’t care what you do, but you can’t come and officially move across to the group, because I think that would have caused problems. That would have looked as though we were trying to bring people in. As it was, we were able to work very well with the theoretical physicists, there was an established group and they did well. He never was accepted as a member of the group and the people were very conscious of this, but he wasn’t one of the group, he was a theoretical physicist working with the group, he wasn’t one of the solid state physics and devices division. And the same thing with the materials group, the materials group wanted to work with us. This was actually largely on the semiconductors, but the same principle worked, that there was, I think the Head of Physics wanted the, wanted a team in the materials division to work with me under my…. got to be careful what word I use, not under my control, under my influence and the head of the division was not happy with that. He wanted them to work through him, and him to work with me, and his team just weren’t happy with that, they wanted to actually feel part of our organisation and we accepted that. In the end I mean the head of division grudgingly on his part agreed that the only sensible way of them working was to work in close collaboration with my device team. We were getting material from Plessey and STL and that was fine, but it was clearly advantageous for us to have a local supply and it was advantageous to them to be in touch with the people who were producing the material, because in this way they actually got ahead themselves. So they were accepted as part of the team, but they were never part of the division. And so it was spreading. I mean…

[27:05]

*Interested as well when you sort of mentioned that if people – I think the phrase you used was if people wanted to come and work with us they could come and work with us, that’s…*

Yeah. I mean…
So was there really that much freedom, people to sort of…

As long as they were doing what their own administration wanted them to do, if they thought it was going to actually improve their output. For instance, and again we’re getting away from displays though the principles are the same, people were talking about… I hope this is no longer classified, I don’t think it can be. But essentially the electronics group, which was different from the physics group, was given the task of developing a fuse for mortar shells that would explode the shells when they were a definite distance off the ground. Now, that is not an easy thing to do, to actually specify when a shell is going to be, shall we say, six feet from the ground and not four feet and not ten feet, so how do you do it. Well, one way to do it is obviously acoustically, but that’s maybe won’t be so reliable when the thing has been launched from a mortar or something. But then what’s wrong with radar, and remember we had developed small radar sets that essentially could detect. I mean just as it can detect a bullet you can detect the ground that the bullet’s approaching. You know you’re going to be, it’s the only thing at one speed, it’s not too difficult to organise yourself so you can measure distance. So it’s an application for a miniature radar set that goes in the head, but it’s got to designed properly, it’s got to be engineered, it wasn’t the kind of thing that the physics group could do, but the electronics group wanted to do it and they wanted to use our miniature radar sets. And so they joined our group in what they were doing and got advice on the miniature radar, which they could do perfectly adequately with a little bit of guidance on how the device itself worked. It worked all right, except once, it all sort of fell to pieces and we discovered that the workshop had used the wrong screws for fastening it together because they’d run out of hardened steel or something or other. We were pretty irritated at that because it was quite an expensive trial that had failed. But that was the kind of way you worked together, that was, I mean they weren’t doing it because they wanted to work with us, they wanted to work with us because they were doing it. But of course they developed the idea of doing it from us and there was another one that was again very interesting. It was… there was alive to the business of civil applications they were working, [30:40] I’m not sure, we can’t have really still been part of Ministry of Technology. This was a system for oil tankers coming to a quay and if you just think about an oil tanker just coming into harbour and tying up it sounds straightforward, but then you’re told, well, you know, you tell an oil tanker to change its speed or direction and it’s a good five to ten minutes before it takes any notice, because it can’t change in that period, it isn’t like a car. So how do you ensure that you come to a quay and you’ve got to get to zero knots and within a foot of something by programming it from its speed some distance
away. And how do you do the last phase. Well, the answer, curiously enough, is radar and again, you can fit one of our miniature radar sets in. And the reason why we were asked to do it was two weeks before an oil tanker had actually hit a quay somewhere in the South Seas and had done over a million pounds’ worth of damage to both the quay and the oil tanker. So we had heard about this – I hadn’t, this was somebody in electronics that heard about this - and thought it would be a good thing for the Establishment to do and they got a contract from either BP or Shell, I forget which. But one of the recordings, and I don’t know whether this was ever followed up, it certainly was a research contract and was quite profitable to Malvern, and there was a recording they played where it said the scientist has got the control and is by the pilot – no, by the pilot – bringing the thing in and the scientist says – oh, the scientist was on the quay, that’s right. ‘Right’, he said, ‘Okay the first thing is I have you on my screen and we are predicting your approach’. And the pilot says, ‘Thank you very much’. Then he [the scientist] says, ‘Hm, I think you’re coming in a bit fast and close’. ‘Thank you very much.’ ‘You’re really coming in extremely close, you are going to come extremely close you know. I have actually piloted tankers into this harbour many times before.’ ‘Yes, okay.’ ‘We are evacuating the quay now.’ It hit. And that was actually in one of our trials before we got the contract, then we got the contract. We got the contract the next day. And again, this wasn’t my team at all. I knew what was happening, obviously, but it was the electronics group had built the radar and built [34:05] all the control systems and was running the trial, but they would link with our people on how did the device work, what was this, how did they measure that it was doing the things. I mean these would be radar people but they would be linking with our people, it was the way the whole system worked, and clearly I knew what was happening. And when it came to staff reports and things I would often be asked for a note on how the people had performed. And invariably they’d all performed very well. Does that clarify things?

A bit, but it leaves me with a question of who’s telling you what to do?

Oh, nobody told me what to do. No, there wasn’t anybody who could tell me what to do. There was nobody in a position to tell me what to do because of my individual merit thing. If I hadn’t been successful there might have been a problem, but well, there was a thing. Not all the people in the group wanted to progress… [telephone ringing]

[pause in recording – 35:35]
Where were we?

*I just asked you who was, who was telling you what to do?*

Who told me what to do. Well, in the same way I couldn’t tell the individual merit people in the group what to do, nobody could actually tell me what to do because I was trusted to do the things. Now, I was saying that the physics group had a fair amount of freedom anyway in what they were doing because they were further from the sharp edge, but of course if they hadn’t produced either papers or results then the head of the group would actually have to talk to the Deputy Director and the Director about results and things. But there were various things that happened, though I have to admit that in some of them I was the judge. For instance, there was a competition all the time in the Ministry for a central fund for research things and there were various projects put in. And I was supposed to look after this and ensure in an unbiased fashion that the money was shared around. But the problem wasn’t then to select projects for Malvern and Farnborough because they were an order of magnitude better in their depth than anything that was coming from the other establishments, it was more to set up some kind of structure so that the other establishments, like Fort Halsted which was much more practical, as was Portsdown and Portland, Weymouth to – and the smaller places – that they got something to encourage them to do things that weren’t directly under the instruction of headquarters, you wanted to get more people, and so did headquarters, get more people thinking of novel ideas. And there was no shortage of that in Malvern or Farnborough, that was more a question of the people there convincing somebody in the administrative role in their own local organisation that this was worth doing. So there wasn’t much control in that way there and as far as I was concerned there was even less, because to some extent I was looking at programmes more generally as well as my own and there are a lot of things that we did. There were requests coming in sometimes from the forces for things to be done there and then we – we took those very seriously and did work on them and gave advice. One of the people, for instance, at quite a late stage had left and said people could go up the individual merit or they could take organisational posts and there was one in our group, well I actually mentioned him earlier, he did, for the Claribel he did the direction finding, Adrian Mears, he took a post in headquarters and came down to look at what was happening in displays and he said I don’t think that there’s much happening on displays now, he said, we’re sort of running out of steam, there’s not a lot happening. And I said, ‘Well I don’t agree with you Adrian’. He said, ‘No’ he said, ‘I’m not going to give approval for this in future’. So I said, ‘Fine’. So he went away and the next year he came back and he said, ‘I’d like to look
at the programme’, he said, ‘You’re still working on displays then?’ I said, ‘Yes’. He said, ‘Well’ he said, ‘I thought it was stopped’. I said, ‘Yes, you did say that didn’t you, Adrian?’ He said, ‘You’re not taking any notice of me are you?’ I said, ‘No, Adrian, should we?’ He said, ‘You should take notice of me’. I said, ‘No, Adrian, no’. So he went away, came back the next year and we still hadn’t taken any notice of him and he didn’t, I mean there’s nothing he could do because essentially we could obviously call on people who were higher up and they were very happy with what was going on. Well who wouldn’t be? It’s a poor organisation that doesn’t respond to success on the grounds it doesn’t fit in with formulae.

[40:15]

What constraints are there on then, if any?

Are there?

Mm, are there any constraints?

Oh now it’s quite different.

What about then?

The constraints were very much on what the military needed and wanted, but you, you always try to be ahead of them. For instance, I remember talking to somebody who wasn’t that senior, he probably was a colonel, and I was saying ‘What’s your view on the need for seeing through haze?’ And he said, ‘What do you mean, seeing through haze?’ I said, ‘Well, imagine you’re in a desert and you’ve got the heat haze in a desert, would you like to see through that haze?’ He said, ‘You can’t’. I said, ‘I know you can’t, but would you like to?’ And he said, ‘There’s no point in even thinking about it, I mean anyone knows that light travels in straight lines, the haze is there, you can’t see through the haze’. I said, ‘If you have a magic box that could enable you to see through haze, would you like it?’ And he said, ‘I’m not bothering even to think about it because there is no magic’. Well, it was a system called adaptive optics that I wanted to use, which essentially corrected light beams. I didn’t know whether it would… I didn’t know how important a topic it was to the military and I didn’t get anywhere from him either because he just refused to believe in it. And there was also a question of robotics when I was involved with DSAC [Defence Scientific Advisory Council] and they were talking about robotics and drones and
things, was there a need for this and for many years there was resistance to actually having aircraft controlled, from headquarters and you could point out to them the advantage of this but they wouldn’t do it. So quite often it wasn’t a question of them asking us to do things, though that did happen occasionally, but often it would be the other way, that the people would be thinking of ways in which warfare could be carried out, very often with less risk of life. But you did get involved and you got involved in consultations on things like laser damage and things and I have mentioned already Claribel and the things, well we didn’t know that there was a sniper problem until somebody came down and told us there was a sniper problem. Once they did we used our nuts on this to work out ways of doing it and we would always take these things very seriously, because we knew in the end that the lack of direction came from conviction that we were doing a good job, and that was a good job in different ways. And of course, we also had industry behind us quite often because of the way in which we handled the contracts, that they would be looking for support for their research, support both in the funding and in the direction and show that what we had asked them to do was going to lead to them having product. They weren’t interested in doing academic research, that isn’t what they were there for.

[44:10]

*I was wondering as well, I guess working on a lot of military systems, did you ever have any qualms about essentially designing weapons?*

Never had to design weapons.

*What about things like infrared missile seekers, that sort of thing?*

Well, that kind of thing, I didn’t actually have a lot to do with that, but I would, I had no qualms in developing missiles that actually were more effective in shooting down aircraft. I mean after all, I suppose I reasoned that the pilots were coming over to do damage and you were stopping them from doing the damage. I never had to work on atomic weapons or anything like that, so I didn’t have to face the moral dilemma. I mean essentially, almost everything I did was defensive, so it made it easy for me. I don’t know, I never had much truck with people that accept money from the public purse but aren’t prepared to use their brains that are funded by that money to actually refuse to do things in the public interest. You then get what is the public interest, well I suppose the public interest at the time is what the government says is the public interest. It’s a bit arrogant to actually in your employment to protest about it. Of course that doesn’t mean to say in
your private life you can’t do things against it. But you always have to remember where your funding comes from, that it’s quite a privilege to do work that is funded by the public purse. Sometimes academics don’t recognise that their money does come from the public purse. And I used to be a bit irritated when we offered to fund work in universities and they would refuse it. Not only refuse the funding, but actually would refuse anything which defence was interested in, which seemed to be a bit sort of exaggerated. But people decide on their own priorities. I would have no objection to somebody who was funded privately from deciding what he wanted to do, but to some extent, if you’re funded from the public purse you do owe some responsibility to the public.

[47:25]

There’s an interesting phrase you have used a number of times, not just today but in other sessions as well, which is ‘the system’. You know, the system thought I’d done well, the system didn’t like that. I was wondering what was the system?

Yeah, I don’t like systems. I used to argue, when I… it was a very curious position because in some respects I was viewed as a rebel, and yet very often I was asked to talk for, on behalf of the organisation and for some years I actually lectured on management to the Civil Service, which is odd isn’t it, since I had a position that was supposed to free me from management. And then I would say things like, if anyone tells you that you should do something or do something to somebody which puts them at a disadvantage but is good for the system, you should say that’s a contradiction in terms, because there is no such thing as the system. The system is made of individuals and you should never accept anything that’s bad for an individual and say it’s good for a system because it can’t be true. So if anyone says that to you, you say no, that’s not true. It may be you can explain this as being temporarily apparently a disadvantage, but in the long run it’ll be good, and then see if the individual accepts it. But, you should never accept the promises of senior people because they have a habit of changing. The senior people have a habit of changing after they have given you their opinion. And this was coloured by my own experience in the Civil Service. If you remember, right at the beginning, when the person had promised me a promotion to Scientific Officer, Junior Scientific Officer within three months and knew that he was leaving. And that’s also happened in other places where I’ve seen that. But that was the kind of advice I would give people. I don’t like the talk of a system, it’s a shorthand anyway. What I mean by the system, I mean collectively the senior people in London who will be looking at what is happening and there were a number of establishments that did have problems that… The
public service can be attractive to people who want an easy life because they feel that there won’t be much supervision and as a result they aren’t very productive and that can be very inefficient and then it does need somebody in a senior level to actually step in and indicate that there are more efficient ways of using the funds. So you can’t generalise on these things, but on the other hand, if you get a group that seems to be producing results of all kinds – financial and general profile and reputation – why interfere with them. There may be specific requirements that you need satisfied and it may be that these are the best people to satisfy it, but then it’s a question of persuasion. But if you’ve got a good reason most of these people who are working efficiently are quite logical in what they’re doing and they can be persuaded. I don’t know. Does it make sense?

Mm. Interested in the fact that despite not liking the idea of a system though, you’ve used the phrase an awful number of times.

Well, I use it as a shorthand. It isn’t the total system, but it may be the government system, which is obviously shorthand for the politicians and the civil servants at the top, it may be the Ministry of Defence, which again is the civil servants and the military people at the top, it may be the establishment.

Did you ever feel part of a system?

Erm… I always felt part of the Establishment where I was working and particularly a part of the groups in which I had influence. I’m not sure I felt an intrinsic part of the Ministry of Defence, though I always felt I had the responsibility to and I never questioned that when the need came to work with them, but that doesn’t mean to say that I felt that I was interlocked with them, and indeed when there were opportunities of joining them officially, I always resisted them. We haven’t come to the time when I was Deputy Director for a time, but we will get to that I’m sure. Again, I said that curiously enough, although I was thought of as a sort of rebel in some ways and willing to have arguments about things quite often, I was also asked to do things and I was asked to write a recruiting page for the Civil Service booklet that was sort of sent out to people, to universities to recruit them and I was actually the most senior person, that was when I was a Deputy Chief Scientific Officer and I was asked to write the thing. And I still remember the first sentence was, ‘I never think of myself as a civil servant’. They left it in. Thought they might take it out, but they left it in. ‘I never think of my…’ And I didn’t, I thought of myself as a scientist
and engineer. I suspect that quite a few of the other people in the group also thought the same way. [54:33] I was recruiting somebody at Baldock many years earlier than where we’ve got to and he was okay, he wasn’t remarkable, and as he was, after I finished I said, ‘Have you got any more questions you want answered before you go?’ and he said, ‘No, I don’t think so. Oh yes, what’s the pension arrangement?’ And I looked at him, I said, ‘I don’t know. I don’t know what the pension arrangement is, I’ve never really thought about it. You’ll have to ask one of the other people, they may know’. And I thought, what a strange question. Well, I suppose it wasn’t really a strange question, but I can only say that was my answer at the time. I think I then did start looking more deeply into the pension, I thought oh my God, I don’t know what the pension arrangement is. So no, I didn’t think of myself as a civil servant.

Could you define as well what you meant by, sometimes it was, I felt like I was a rebel in the system, or people made me feel like a rebel. I can’t remember the exact phrase you used, but…

Yeah. Well, I didn’t respect ranks you see in people, I tended to respect talent and I did get into some arguments with people who thought that I should be more cognisant of the fact that they had a certain seniority. Maybe they were asking me or one of my people to do something and I wouldn’t necessarily accept and in general I had different views as to what we were there for and of course I had had the arguments with Sutton and people did know about that, I mean there weren’t that many people who’d been thrown out of an establishment.

While we’re sort of talking a lot about working arrangements as well, I was just wondering if you can give me an idea of, I guess what the atmosphere was like while you were working on liquid crystals – what did you all think about this?

[56:40]
It changed with time. I think at first most of the people were probably suspicious and concerned and nobody had worked on liquid crystals, we did not recruit a single person to the group who had worked on liquid crystals. There was no experience, this was pretty unusual really because when you take people on they come from academia, they come to join and they want to at some extent exploit what they have done before and I mean we had recruiting into the group, we didn’t necessarily have people recruited to join my team, though that would be open to them and a number of them did. But we would question them on what they did and I still remember Peter Raynes when he came. The reason why I recruited him was his answer to the question, ‘What
would you like to do?’ And we did say to them, ‘What would you like to do?’ and the answer we normally got, which nearly always was a death wish because we didn’t do it, was, ‘I want to exploit what I have learnt during my PhD, so I don’t mind what I work on but it’s got to be electron microscopy’ or ‘It’s got to be metallurgy because that’s what I’ve done’. Peter’s answer was, ‘Well, I don’t really care as long as it’s not superconductivity’. I said, ‘Why not superconductivity, it’s a good subject?’ He said, ‘Yes, but I’ve worked on it for three years, that’s quite enough’. I thought, yes, good man. And of course with liquid crystals there’s nobody could come along and say I’ve worked on liquid crystals so I want to do it. So it would be people who’d worked on other things, but thought displays were interesting. This is talking about people coming in because you asked about liquid crystals. So that was easy. The other people coming in to semiconductors were very often people who had worked on some semiconductors in some way or they’d, they essentially were physics graduates had worked on things, but with liquid crystals that wasn’t. So the spirit was one of curiosity, it’s interesting, it’s pretty unknown so there must be a lot of scope here, and we’ve been given pretty well a free hand and we’ve got support staff. And the other thing we had of course was this team of women, of mixed ages who would make devices for people, which is something that didn’t seem to be around in other places. These were industrial workers. We could recruit people from, they were the industrial staff, they weren’t non-industrial staff, there wasn’t the same headcount there, largely because they weren’t paid so much and I don’t think they had much protection, staff protection. I don’t think they got pensions or anything like that. And they often would be part-time as well, but they developed skills and I think they’re still there actually. Well, I don’t know now. QinetiQ’s gone through some changes recently. But certainly what was set up there that came as an inheritance from my time at Baldock. I did not invent the idea, I latched on to it as being a valuable way in which you could take the stress off scientists. I mean it’s all very well to sit down and work out a way of putting a tin dot on a piece of gallium arsenide with stearic acid but you really don’t want to do that a hundred times, but when you’ve worked out what to do you like to have the idea that there’s somebody who can say, ‘Now, Dot’ – and we did have one called Dot who was very, very good – ‘Now, Dot, this is how you do it, I want you to make me a hundred so I can measure them’. And Dot was actually the – they had a hierarchy too – Dot was the head of the group of young women. They weren’t all young, women, I mean, well I mean we would advertise for them locally and they would come along and someone would select them. I didn’t generally select them, they’d just be there and I’d see a new face and say hello, what do you do, what’s your name, and they would say ‘I’m Amy’, or something, ‘I’ve joined the group of valve assemblers’, I suppose they were called, or I don’t know what they really were called. But yeah, and that was [1:02:10] an
advertisement certainly where people could see there was an infrastructure that they could latch on to.

*Are there any particular difficult moments in the story of LCDs that you talked through earlier? It sort of seemed quite straight…*

Tend to forget about them, I suppose. Oh… you tend to forget the years of frustration but there were difficult… you see, I said we started in 1970 and we were successful, or George was successful in ’72. I can remember ’70 because I know that’s the year we really started the programme going. ’72 I can remember as the year of the patent. But what happened in between? Now that was complete frustration, complete frustration with making more and more materials and all of them failing and not seeing there was an answer. This is the problem in research, that you can’t be sure there is an answer. With development you can be pretty certain that you’re going to improve the thing you started off with, that you’re going to work on it and you’ve got a sort of foothold in the field and you can build on that, but when you start off, is there a liquid crystal which is stable and that works from 0°C to 60°C. You can’t say yes there is, but George said, there must be and you then say well, do I trust him? Well, what else can I do? I want to get into this field, I’m pretty certain that this field is worth us investing in. If it had gone on longer than two years, would I have continued it? Yes, probably. If it had gone on longer than four years, would I have continued it? No. Even I have my limits, yeah. You have to accept sometimes that you’re wrong and I’ve got a few examples of that which I haven’t specified, but they tend to get forgotten unless somebody who was there reminds me. Now that’s the early stages. The next six years were extremely frustrating in liquid crystals, but they weren’t because of the liquid crystals. They were because of the need to make more and more complex displays. [1:05:25] I mentioned the number of pixels that you’ve got and if you have a seven bar numeric and you’ve got six numbers there, that’s forty-two picture elements and that’s very easy. If you get an alphanumeric and you’ve got thirty-five dots and you’ve got six of those, that’s 200 and you can even imagine that you can put a positive and a negative contact to each dot. If you start getting much beyond that, you start thinking about how can I handle that many pixels, I can’t put two contacts on - 10,000? 10,000? Can I put two contacts on 10,000? Mm, going to be a bit difficult isn’t it. So you then start thinking about, well is there another way, and there obviously is another way because you can say, well I’m going to have a matrix of connections; horizontal and vertical and where they cross, if I’ve got a hundred horizontal lines and a hundred vertical lines, where they cross I’ve got 10,000 picture elements. Well that’s better, because I’ve now got
2n contacts, $2n^2$ elements, and if n is bigger; the difference between them becomes enormous. So that’s the key, I’ve got to have my X and Y connections, which is logical and simple until you start trying to do it. And then you realise that if you actually have enough voltage on the X and Y lines, so you say you’ve got five volts on each X line and minus five volts on each Y line, at some cross point if I’ve got a particular X line, a particular Y line, I’ve got ten volts across that. So that seems fine, but what have I got across all the others. And you realise that you’ve got five volts across quite a lot of your display. And then you realise also that if you have this on a matrix again and you start addressing it, that you try and address one point at a time and it’s easy and who the hell wants a display with one point at a time. So you try and address two points simultaneously and then you realise that when you do that you are switching on two points, but now you make a rectangle with those on the diagonal and immediately you see that you’ve switched on the other points on the other diagonal of the rectangle. So that won’t work. So then you realise that the only way you can do this is to multiplex, which means that you put your data information on your vertical lines and you do your horizontal lines in sequence, so you run down them in sequence. And that seems to work quite well, it certainly gets rid of the ideas of the diagonal points and you don’t have elements just coming on immediately, so now you have to look at it dynamically and see what happens over a frame and you realise that over a frame you may have only the points lit up fully that you intended to activate, but you’ve got an awful number of points that have half of the voltage across them. And if you actually integrate over a whole frame, you may well find that the signal you get from a large number of half impulses is as great as the signal you’ll get from a single full impulse. So then you start thinking about what is the law that connects the optical effect with the impulse I’m applying. If that effect is more or less uniform, linear, so that I get twice the effect if I double the voltage, then I’m in deep trouble, deep trouble, because those number of half pulses will certainly add up to more than a single pulse, they only need to have two half pulses to every full pulse and I’ve got the same optical effect. But when I’m multiplexing down I’m liable to have fifty times as many half pulses as I have full pulses, so that won’t work. So what effect do you want? You’re being a bit particular now, you’re asking for an optical effect. Oh, what I want is an optical effect with a threshold. I want to have no optical effect for a voltage up to say, three volts, and then at four volts the effect starts increasing until I get to six volts when I wouldn’t mind if it’s saturated, but I want it to be large at six volts and absent at three volts. Well that’s asking for a bit much isn’t it? Well no, that happens in an LED. Oh, does it? Yes, an LED, you put one volt on an LED and no light comes out, you put two volts on and all the light comes out because that’s the way semiconductors work. Well it’s not the way liquid crystals work. Well, hard luck. So, what am I to do? Well, why
don’t you put a semiconductor in series with your liquid crystal? How do I do that? Well, you’ve got everything happening at the cross points haven’t you? That’s where you’re getting your interaction between the voltages you’re applying and the liquid crystal in between. Yes. Well, why don’t you put a diode there at that cross point? What, you mean stick a diode on? Yeah. Look mate, I’ve already said, I’ve got 10,000 picture elements, how can I stick a diode on every one of those? Oh, that’s simple. How do I do it? You evaporate the semiconductor over the whole surface. Oh, I can’t evaporate semiconductors. Yes, you can son. Oh. All right. So what do I do? Well, you make a thin film of semiconductor. But even a diode doesn’t work as well as I would like it to, it might work for 10,000 but will it work for a million? No. So what do I do? You make a transistor. [1:13:25] What, transistors over the whole area? Yeah, why not? Has anyone ever thought of making transistors over the whole area? Yeah. Who did that? RCA. What, the company that gave up on displays? Yeah. They had a man called Paul Weimer, he was very clever, in 1962 he worked out everything you’d need for displays even though they hadn’t got displays then. And he worked out that you could have a thin film transistor. So we need a semiconductor that you can evaporate over the whole area and then put transistor electrodes on it and make transistors? Exactly. What semiconductors have you got that do it? None. Oh, that’s a shame. Yeah. So what did they do? They used bad semiconductors. Oh. Did they work? Well, for a time. How long? A few months. Oh, what were they made of? Cadmium sulphide and cadmium selenide. Cadmium? Yeah. Isn’t that poisonous? Very. Did people like using it? No. So you’re telling me that we should use a poisonous unstable semiconductor? Yep. But isn’t that what we got away from when we went to liquid crystals and became stable liquid crystals? Yeah. Life’s peculiar isn’t it? So this is no better? No. So what do we do? Get frustrated for six years. And that’s exactly what happened. And people have been given prizes for developing, for suggesting unstable poisonous semiconductors and it doesn’t surprise you, I’m sure, to know that they were never used, because people don’t like using poisonous materials. But we tried them and we tried other things, we tried glasses, I could tell you lots of stories about a gentleman called Ovshinsky who invented a glass that switched and built up a company that was based on it. I will say that every year the auditors said we cannot actually agree that this is a stable situation. The company made its money basically through patents and largely getting licence fees from people who were scared of being sued, even though the devices were never actually successful, but they made an awful lot of them. And they may have had some applications but they were never used in displays of any number, though we, particularly one of the people in my group, Tony Hughes, did spend many agonising hours trying to make stable
glass switches that worked. And we tried lots and lots of other things and that was six years when
we and the world were trying to find solutions to this. And the solution came.

[1:16:50]

*What was it?*

It happened in a strange way, because there had been a group at Harlow and we’d had a lot to do
with STL Harlow. They were in the consortium, they were in the gallium arsenide consortium
and they were also in the liquid crystal consortium, so we knew them very well. And they had a
great interest in optical fibres. They were developed at STL, it was an STL invention by Charles
Kao who got the Nobel Prize two years ago, and the problem in exploiting fibre optic
communication, which they wanted to do, was the quality of the fibres, and they wanted them to
be purer. They needed to be pure as well as being in fibre form. And a man called Henry Sterling
got interested in putting down silica from the vapour phase and he discovered that he could make
silicon from the vapour phase as an amorphous material, a glass. It wasn’t crystalline, it had no
crystal structure, it was silicon as a glass. And he started trying to dope it and he showed that you
could dope it as well, not terribly well, but you could. And he actually made diodes from
amorphous silicon. And it was very successful. So, what happened? Well, you’re used to this
aren’t you, from the story of RCA. They stopped the work, because it was successful. I suppose
they stopped it because it was successful. I mean it wasn’t unsuccessful, if it had been
unsuccessful you could understand it, but I’ve no idea why they stopped it because it was
successful. I suppose it wasn’t going along [with] what was required at the time. And then there
was a group at Dundee headed by a man called Walter Spear and he had as a very able lieutenant,
Peter LeComber, who was a senior lecturer. And Walter got interested in this and they started
working on amorphous silicon and they added hydrogen to it. Now Henry Sterling may have
added hydrogen to it as well, but Walter and Peter certainly added hydrogen to the amorphous
silicon that was deposited from the vapour phase, it could be deposited in different ways as a
glass, and they showed that not only could you make diodes from this by doping p-type and n-
type exactly as you do crystalline silicon, though as a semiconductor it was pretty pathetic. I can
tell you how pathetic it was, that if you say that the mobility – remember, we’ve talked about
mobility of electrons in silicon and I gave you a rough number of a thousand and that means you
get 1000 centimetres per second velocity of the electrons if you have a field of one volt per
centimetre, so that’s a mobility of 1000 - the mobility of amorphous silicon was 1,1 compared
with 1000. So when I say it’s not as good a semiconductor, I’m not exaggerating, it’s a pretty
poor semiconductor. But, if you make a diode from it you find it’s a photocell, that it actually
turns light into electricity fairly efficiently, fairly efficiently. The electrons that come out aren’t
moving very fast but they are coming out and you are getting not quite one electron per photon,
but you’re probably getting sort of three electrons for seven or eight photons. And of great
interest is the fact that it’s sensitive to light and infrared, matching the sun’s solar spectrum fairly
well. So what you have made, what they had made with Dundee was a solar photovoltaic cell
just at the time when people were interested in renewable energy. So immediately the world beat
a path to their door because you could put these things down over large areas and a lot of people
became very interested in them, including the Japanese companies that thought they could see a
way of powering calculators and watches and all kinds of things from very simple evaporated
silicon. [1:22:20] And Walter and Peter were at the top of the world, everybody was beating a
path to the door, they were turning out papers, they were giving invited talks, everyone was
interested in funding them and I couldn’t get a word in edgeways, because I could see that this
was the magic material that we wanted, that it would give us a thin film transistor, and what is
more, it was made of silicon so nobody could think it was poisonous, could they? And we
calculated that that mobility of I was quite sufficient for us. It wasn’t as good as we’d like for all
purposes, but what we needed was a switch, we just wanted the transistor switch on and off, that’s
all we wanted for the elements. And this would do it for us, so what we needed was for Dundee
to make us one, or perhaps ten, thin film transistors. Would they? Like hell. I’ll give you
money. Don’t care. Give you lots of money. Still don’t care. What do I need to do to persuade
you? Nothing, we can’t be persuaded. We’re doing very well, thank you very much, out of these
solar cells, everyone wants our solar cells, everyone wants us, we’re interested in more research,
making the solar cells better, putting up the efficiency and please go away. So, what could I do?
I’d offered them a contract, I’d offered them contracts. I’d spoken to them. Walter was adamant.
Fortunately Peter wasn’t quite as adamant. Peter was younger, he wasn’t as wedded to the things
that were happening, because fairly obviously Walter was taking most of the credit because
Walter had had the ideas and was doing it, he deserved it. But Peter agreed that he would make
me some transistors. And at Christmas Eve 1978 I got the best Christmas present ever, a little
parcel that had a dozen thin film amorphous silicon transistors and by lunchtime I had connected
them up to a liquid crystal display and shown they switched a liquid crystal display. I still don’t
know if Walter knew, and they’re both dead, and neither of them would say. All I know is that I
got them, it was certainly Peter’s handwriting on the envelope, and it worked and it was
obviously the solution if they were going to live. We still didn’t know this. At the time there
were suggestions that amorphous silicon transistors – amorphous silicon cells – changed with
time and indeed they do. There’s an effect called the Staebler-Wronski Effect, which is S-T-A-E-B-L-E-R hyphen Wronski – W-R-O-N-S-K-I - see how considerate I am – Effect, which essentially says that light will induce traps in the amorphous silicon which cannot get dispersed and they trap your electrons after a time, so the effect drops. And that’s one of the main reasons why amorphous silicon is not used these days in photovoltaic cells for generating electricity. It is still used for portable equipment and is quite convenient and the fact that its effect drops after a few years is of no terrible concern to people who are making equipment which isn’t going to be used for that long anyway. For renewable energy it’s another story, so you can veer from it. But it is used for material for that. It’s a very interesting material physically and is studied widely, but as far as we were concerned it was the way through and that was 1978. [1:27:05] So now we had our stable liquid crystal, 1972, our twisted nematic effect even before that, right, and now we had our active matrix element. It’s now called an active matrix. The one without any devices on it, just the X/Y lines, is called a passive matrix, which we’ll get back to in a minute. But now we had the circuit element for active matrix and that is what is used, 1978 it took them a long time to learn how to put them down and how to do it so they all worked, but now you can evaporate them over, well I think it’s mark eight or something in the size of displays, they’re now about twenty-eight, six threes are eighteen, twenty – probably twenty metres by ten, they make glass. Two glass pieces that they put together, separated by five microns over the whole area and they cut them up to make a number of those, six of those or something and they have twenty million transistors on them and they all work. Or more or less all of them work, enough so that you can’t see the difference. But that essentially is the way they work, the actual liquid crystal effect has changed a bit over the time and the way they’re lit from behind has changed. The basic effect is still the same, the materials have changed a little bit as time has gone by to make them work faster and things, but essentially you can say the physics was more or less finished in ‘78 and after that it was just engineering, some pretty inspired engineering. But there had been an interim thing. [1:29:20] We had been frustrated in the bit in between and this is where our Merck man, Colin Waters, came in, because Peter Raynes had got interested in really just what happened if you changed the device structure slightly, and he’d got interested in what happened if you had a twist of more than 90°C. I had explained to you earlier that you built in a twist of 90°C into the liquid crystal and that was the way in which the twisted nematic worked. The problem with the twisted nematic was that it was slow, the speed with which it relaxed back, you could increase the speed it was turning on by increasing the voltage, but when you took the voltage off, it just relaxed back and particularly at low temperatures this could be as long as 50 milliseconds. So you could see memory in the display and Peter was interested in whether you could speed this up
and he thought if you actually put in a bigger twist, say 270°, it might go faster. And he was right, it did go faster, but what he hadn’t realised was that also he was going to change the optical response so that it was no longer linear. So in fact it responded with a threshold, exactly what we wanted from the thin film transistor, so that you got a much bigger effect at high voltage than you got at half the voltage, that it was almost a threshold, not quite, but there was enough so that you could make a laptop computer display. You couldn’t really make a television, but you could do a laptop computer because the quality you wanted from that was better. So in between us doing the amorphous silicon, Colin Waters and Peter Raynes invented the super twist nematic display. And that was done a few months before a team at Brown, Boveri – I said they were linked with Hoffmann-LaRoche – did the same thing. But we were first by about three months. They always claim they invented it because they put in some more details, but Peter and Walter [interviewee correction: Colin] also did this, but people then wanted to license it and I’ve no doubt that they licensed both sets of patents to be clear, and that was the invention that brought us in a hundred million pounds, the super twist display, which was used in laptop computers for a number of years, because although I’ve said that the physics problems of amorphous silicon were solved, the engineering problems weren’t solved for several years afterwards.

When abouts is the super twist display invented, just so I’ve got the narrative straight in my head?

When? I’d have to look up to be careful. I would have thought it was about ’78. I can look that up and check the exact dates of the patent and things. But it was, I’m pretty certain it was before 1980.

Was this the device you said you’d advised them not to pursue or something?

Yes. But Colin wasn’t supposed to be working on devices. He was always in the lab working with Peter and I kept nagging him to say look Colin, you’re making it difficult for me, the last thing I want is for you to be successful because how do I sell that to Merck, because you’re paid to work on materials. He said, ‘Yes’, he said, ‘I will change, I’ll just finish these experiments and then I’ll change’. What can you say?

Shall we take a break?
Absolutely, yeah.

[end of Track 19]
The other part of this I was going to ask you about was George Gray. You mentioned when he first got involved, that meeting, were there any alternatives?

No. No. I can honestly say that meeting was distinguished by the lack of knowledge of liquid crystals among all of the rest of the audience who had professed to be the best people that industry could provide. There was nobody who knew anything about liquid crystals apart from our group that had come to our talk. There may have been a few chemists, but I don’t think so. I don’t think there was much interest in liquid crystals.

How did the actual link-up take shape after that initial meeting?

There had to be a delay because we had to set up a funding stream. I couldn’t place contracts myself, the contracts had to be placed through CVD, so there had to be an Establishment requirement for there to be a contract and it was purely formalities to be arranged. There was no opposition. It wasn’t that, it was just this was the first contract we had placed on liquid crystals. We had some contracts on displays, though the actual programme hadn’t taken form. Displays were electronic components, they were mostly cathode ray tube displays, but there were other numeric displays which were being made. So there were some contracts going and as time developed, and they could have been developed actually before 1980, that I was actually looking after some contracts on plasma panels and things. It certainly developed later because I can remember complaining bitterly to STL that I wasn’t getting any life data on the plasma panels they were making and they said, ‘You don’t seem to appreciate the problems we’re having in measuring the life of these plasma panels’. I said, ‘What’s the problem?’ They were saying, ‘Well they die too quickly’. [laughs] I thought, that’s interesting isn’t it, they die too quickly for us to do any life tests. Yes. So I was involved in that and this generated so that I think that we did get a Display Devices Committee. There would be committees set up for different things; there certainly was a Semiconductor Devices Committee because I think that I was either chairman or deputy chairman of that. There were other components, radar components and things, but there wasn’t the Display Devices Committee for some time, but then we had one and we could get contracts launched through them. But it had to sort of be organised and Leslie Large, as I said, was the person entrusted with that and it will have taken him a few months to sort the thing out. Meanwhile I would have been in touch with George Gray and told him that we
were going to place a contract with him to work on it but I would like a proposal from him. So I had to have a proposal, a costed proposal. Not costed in the way it is today, but basically saying how many people would be working on it and what the cost would be. So I would have had that from George ready for when Leslie had got the reception of it worked out. But it probably, it probably would have taken us a year to get that sorted.

*What sort of chap was Gray?*

Very down to earth. He’s a Yorkshireman I think. You will find him in Wikipedia of course, he’s very well-known now. Then he was, I think he was a senior lecturer. I don’t think he was a lecturer, I think he was a senior lecturer. I could work this out though, maybe – let’s think – he is about my age, he’s certainly in his eighties, so he was probably a senior lecturer, he’d have been thirty-seven, wouldn’t he. May even have been forty-seven, yeah. 1970. Twenty-five, forty-five, yes he would have been a senior lecturer. He certainly wasn’t a professor then. Doesn’t like wine, he likes beer, can be very embarrassing. If you go to a posh dinner where he’s being honoured and they’ve brought out the finest wines and present him with them and he turns his nose up and says, ‘Can’t I have a pint of bitter?’ And they say, ‘Oh all right’ and they find him a pint of bitter. I don’t know whether he does this in Japan. He got the Japan Prize, which was not trivial, £100,000 or something. All kinds of other awards of course; Fellowship of the Royal Society. Intriguing, you see, that a number of people who were associated with the work who became Fellows of the Royal Society and honoured in various ways, Fellows of the Royal Academy of Engineering and medals all round. [06:20] Yeah, it was a very successful time.

*What sort of working interaction did you have with the group at Hull?*

Oh it was very close, very close. I mean Peter in particular was working with them because Peter did understand organic chemistry so he could make suggestions to them. You have read *Anatomy of a Discovery* haven’t you? Didn’t I give that to you? If not, I’ll give it to you. I wrote that some years afterwards and it describes how we did it. It won’t describe the interaction, but… it was very close because they were making the material, our people knew what they were doing and we were testing the material. Meanwhile I was beginning to talk to the Department of Health about toxicity and things, because people had raised this before so I needed to check this. I knew this was going to be the kind of question which was going to be raised by the Ministry if by no-one else and Sutton had taught me that you find the answer to the questions before they’re asked.
because it’s easier to divert attention if you know what they’re talking about. So I knew that we would need to have a – there had been some suggestion liquid crystals were carcinogenic so I wanted this tested early on. So we were in touch with the Ministry of Health quite early on as was later on, BDH.

_Could you give me an idea of what – a practical example perhaps – of what that close co-operation actually involved on a working basis?_

Well, it wasn’t difficult to buy liquid crystals and it wasn’t difficult to have a laboratory experiment, so we will have had liquid crystal samples that we were measuring. You could actually get liquid crystal devices, not very stable ones, but they would last for you to do some experiments, so we would have had access to the kind of devices which were being put on sale, or that were being sampled. And the people would be getting an understanding of how these things worked and we would be doing experiments in alignment and things like that. So it isn’t that we couldn’t do anything until George had made the things, it’s that we knew that what we were doing had no long term significance in terms of the material, that we knew that we had to have the material otherwise we couldn’t get on. But there were materials being produced by Hull and some of the materials were new materials and we didn’t know how they would perform, but during the two years I think George worked on at least four families. So he would produce the crystals and we would then test them for life and how they worked in devices. And also we would check what structures they had. You have this smectic, nematic, isotropic change with temperature and we would want to know what temperatures these things happened at. Well, you had to do that to make a twisted nematic display. So we would be making displays and commiserating with George when the things died. No George, sorry, this doesn’t work. Oh, blast, we’ll have to think of something else. It was two years, it’s a long period.

[11:00]
That’s the other thing I was going to ask you about was happening over this period as well, which you mentioned at the start of today, was continuing work on semiconductors.

Well, that’s a whole long story and I don’t know if you want to really start on it because this goes on for ten years, which I didn’t realise. I thought that I’d more or less given up semiconductors when I started on displays, but in fact I discover that my responsibilities on semiconductors had increased considerably during this period so I was actually speaking to the UK community on
semiconductors during all this period, going between '70 and '80 actually. I hadn’t got out of semiconductors. In fact I hadn’t made a reputation on displays as yet, but now I found I had got a reputation on semiconductors and remember, semiconductors were becoming much more important, the compound semiconductors had been more or less ignored until the 1960s and it wasn’t, remember, until ’62 that the first semiconductor laser was made and then ’64 before we made the microwave devices. And it was, as time gathered after that that the importance of gallium arsenide became clear. Previously people wouldn’t even have admitted they were working on it. Now it became popular, and of course with our history of having worked on it for some years, we were becoming the centre of attraction and we had the Gallium Arsenide Consortium, which was working pretty well together, which was making a lot of progress, and we were still linked with the American laboratories, so all of that was taking shape and began to develop really in the late sixties. So here I had the two things; one was more mature, but not entirely mature. Gallium arsenide was still a material that was more specialised, that it was clear now it had applications and one of the things that was developed, and it wasn’t developed by our laboratory, but it was developed under CVD auspices, and in fact I was the monitor, was a transistor of gallium arsenide, and we did make the transistor. It wasn’t red hot, but it did work, and it worked at a higher temperature than silicon transistors and people were interested in it because of its frequency response, that it could go to higher frequencies than silicon transistors did, so it could latch on to the silicon interest and the chip interest and as time went by people became more interested in gallium arsenide chips and still are, and gallium arsenide is particularly interesting because it has a combination of high frequency response because of the high electron mobility. I said silicon had a mobility of 1000, in round numbers gallium arsenide has a mobility of 10,000. So you can see the advantage there of going to higher frequencies. It’s not quite 10,000, it’s 10,000 if it’s pure, but it’s sort of an order of magnitude more than silicon is. And you have that and you’ve also got the photo effects. So you get the possibility of having an optical type of circuit which people have worked on. But as I say, we will come to that because that is the story that runs in parallel.

[15:10]

In that case I think it might be a nice way to finish today by discussing life outside work a little bit while you’re at Malvern.

Yeah.
You mentioned arriving and your children being in tears at the prospect of moving there. How did you settle in?

It took some time. In the first place we had to have housing and the Ministry found us a house. This is one of the things that the Ministry of Supply seemed to have under better control than the Admiralty had, and they had houses which were part of the establishment effectively. There were groups of houses, and we were given one though we knew we had to, we wanted our own house. We’d sold our house in Hitchin and we wanted to move to Malvern and it took, I think, probably about six months before we found a house and moved in. But that was all right. We found schools for the kids, I’m not very certain of the… the timing of this. Lindsey was just coming up to school age, so she will have fitted in. They both were at a fairly modern… trying to think. Yeah, they both were at primary school. I think Karen was probably about nine and Lin about six I think. I might be able to work this out. Let’s think how old I was. This was ’64, that’s right. So I, what was it, ’64, 25 is 40, I was thirty-nine. Yeah, Karen was probably nine and they were at a very modern school, very new with a modern headmaster, and we had some interesting episodes with him because his methods were modern. He was very interested in italic handwriting, which puzzled us. And he was very interested in the less advanced student, he wanted to push the average student on, which is admirable, but not so great if you’ve got children that you think are better than average. Lindsey got into trouble relatively early there, because Lin always had strong views on food and she wanted to be a vegetarian from the time she was six or seven, because she said she liked animals more than she did people. So she wouldn’t have minded eating people but she didn’t want to eat animals. So we did have problems with her, her favourite meal when we went out was egg and chips, she was happy with that, but she really didn’t like meat much. And that led to some interesting situations in France which I might get to eventually if you’re interested. But now I got a message from the head, would I mind coming to see him about Lindsey. So I went to see him and he said, ‘We really wonder if you would mind Lindsey having sandwiches instead of having school meals?’ So I couldn’t quite see why this should be something… I said, ‘What’s the problem, I mean won’t she eat the school meals?’ He said, ‘Oh that’s not the problem, that’s not the problem’. I said, ‘What’s the problem?’ He said, ‘She’s persuaded the whole school not to eat school meals’. I said, ‘What?’ He said, ‘Yes, she agitated in her own class and then generally got them to agitate with the rest of the school, so the school won’t eat its school meals now’. I thought oh, oh. [20:00] So that wasn’t too great and she wasn’t too popular and in the end we moved her to another school which we thought she wouldn’t like because it was a very old church school in Clarence Road, which we weren’t too
thrilled about because we’re not churchgoers and we didn’t really like the sort of association. Though in fact it wasn’t aggressive, and we also were a bit concerned that she might miss moving from this beautiful modern building to a rather dilapidated and old building that was really not up to modern standards. And after a few weeks we asked her how she was getting on, what do you think of it? She said, ‘What do you mean, what do you think of it?’ And we said, ‘Well, things are different aren’t they in Clarence Road from they are in Pickersleigh’. And she said, ‘Oh, I don’t know what you mean, it’s school’. ‘Oh’ she said, ‘I know what you mean, the washbasins are at a different height. Yes, they are a different height. The washbasins are much lower in Clarence Road, it is odd. Is that what you meant?’ And we thought well, she’s obviously settling in. Meanwhile, Karen who was a very bright child, we’d had trouble with Karen in Hitchin because the school had reported that at one lesson she’d just got up, had gone to the cloakroom, put on her hat and coat and was ready to come home. And we didn’t know quite what the hell to do about this. So we talked to the school and they didn’t… they said Karen was fine, there was no problem, she was coping with the work and everything, but there was something funny going on. So we in the end got her looked at by the area psychologist or psychiatrist – psychologist I think it was – who reported back and said there’s nothing wrong with the child, the point is that she takes an adult view of the lessons and if there’s something she finds unpleasant she sees no reason why she should stay and listen to it, so she gets up and wants to go home. That’s a very adult kind of behaviour, there’s nothing wrong with her. He said she is thinking way ahead of her group. The thing I should recommend is that she moves up one year, where she will find that the work there is testing her more and there’ll be less opportunity for this. So, the school agreed, she moved up a year. Now, Pickersleigh Road, the head again called me in – I’m not sure which was the order of these two, the Karen one could have been earlier than the Lin one – but he said, ‘We’re having problems with Karen’. I said, ‘So I understand’. And he said, ‘She doesn’t seem able to keep up with the work’. I said, ‘Really?’ He said, ‘Yes, we’re wondering about how good she is’. I said, ‘There’s no question about how good she is, she’s been examined, she’s one year ahead of the rest’. He said, ‘What?’ I said, ‘Yeah, she was examined by a psychologist in the area and she’s one year ahead’. I said, ‘Of course, the fact that she can’t get on with the work may be because she has to do the work for the other children at the table before she’s allowed to do hers’. He says, ‘What?’ I said, ‘There are four children who sit at the table in Mrs Lovell’s class aren’t there?’ He said, ‘Yes, I think so, it’s the way we arrange the school’. I said, ‘Yes, and the other three children aren’t able to get on with their work as fast as Karen, so they ask Karen to do their work first. When she’s done their work she gets on with her own, but sometimes she hasn’t got the time before Mrs Lovell calls on them to do it’. I said, ‘Also, there is a problem isn’t
there, of the children at a table of four being able to observe what is going on’. He said, ‘Why’s that?’ I said, ‘Because one of them has their back to the blackboard and they can’t see what the teacher is doing’. He said, ‘Oh my God’. He said, ‘Really?’ I said, ‘Yes’. He said, ‘But her maths isn’t quite what it should be’. I said, ‘Oh yes’ I said, ‘I’ve got the book here. He said, ‘You’ve got the book?’ I said, ‘Yes, the book they’re supposed to work from’. He said, ‘Oh, what’s the point?’ I said, ‘Well, shall we just look at this?’ He said, ‘Yes’. I said, ‘Well this, it says, you’ve got an exercise, it says what is not well known is the method of multiplication by duplation’. He said, ‘Duplation, what’s that?’ I said, ‘Oh, it’s very simple. If you want to multiply a number by thirty-nine, you first of all multiply it by ten, which is easy, you multiply it by twenty and you add the twenty to the ten to get thirty, you then multiply it by five, which is easy, because it’s half of multiplying it by ten, and then you multiply by four’. He said, ‘Oh’ he said, ‘Yes’. I said, ‘It says there, multiplication by duplation is not often used these days’. I said, ‘I’m not surprised, it’s a terrible method’. ‘Yes’ he said, ‘that does seem strange’. I said, ‘Shall we do the next thing?’ He said, ‘Yes, what’s the next one? ‘It says multiply the following numbers by ten.’ He said, ‘Well that seems easy enough’. I said, ‘Yes’. ‘So the children can do that’. I said, ‘Shall we do the next one? It says, what are the next numbers in the series?’ He says, ‘Next numbers in the series, hm’. He said, ‘I can’t see the answers to that, that seems more difficult’. I said, ‘I’ve tried three PhDs on it, they can’t see the answer either’. He said, ‘Oh’ he said, ‘have you thought of writing a maths textbook then?’ I said, ‘That isn’t the point of my visit, the point of my visit was that Karen isn’t getting on and I’m trying to explain to you why. It’s your school that’s the problem, not Karen’. He said, ‘Oh. Oh’. So we moved Karen, to a private school, which was against our principles as well, for two years, and she got on like a house on fire there and she got her eleven-plus and went to, oh, the grammar school and then she got into Cambridge. That was Malvern and settling in, so it wasn’t straightforward. Meanwhile the kids got on pretty well once Karen got on very well at her school. Lindsey was always a bit of a rebel. She used to have problems with the school which sometimes were due to the school wanting to constrain people to a pattern and Lin doesn’t fit in with a pattern, as she has shown since then. As far as other things were concerned, Betty settled down pretty soon and she had to, she was looking round for a job, she was a French teacher so she had to look round for various jobs, and I think she did supply teaching for a bit in various schools. Malvern has schools, I mean essentially it’s a centre of private schools. And the Establishment, those are the two things which dominate the town. And in the end she settled into Malvern Girls’ College as a French teacher first and eventually as second mistress. We had a nice house that looked out on
the hills and the only problem was, I was away too much and worked too hard, because I did used to go into the Establishment in the evenings to catch up. Yeah. Crazy. Crazy.

*Why do you think you wanted to work so hard?*

It was where I was happy, I liked it, I wanted, I suppose I always wanted to know the answers to the questions before they were asked. And actually, going in the evening meant I actually could do some experiments myself, whereas during the day the rest of the people would want to talk. And I did have reports to write and things, yeah. I didn’t always go in, I used to read, I used to read the literature a terrific lot. Wouldn’t have been possible today, but then you could keep in touch with the literature, so I used to read a lot as to what was happening in the world.

*Was there time for other interests?*

Oh, I played tennis, had a regular foursome at weekends and sometimes in the evenings, but more it was at weekends, Sunday mornings. I think I’d given up chess, I’m not sure, I think I’d given up chess. Yeah, I don’t know. I played the occasional game of football, but not very often. We had quite an active social life with people dining together. Malvern was, I would say, more friendly that way than Baldock was. We had some close friends in Hitchin but that was more a group, here it was more general that you went out and you entertained and were entertained.

*What sort of people are in your social group?*

Well, it was very difficult at Malvern to have people in your social group who weren’t either at the Establishment or at the schools. I mean there wasn’t much else. So yes, the next-door neighbour on one side was the classics teacher at the boys’ college and became Mastermind. On the other side it was an RRE PSO, Principal Scientific Officer, who’d developed a new system of heating his house. It’s all right, I mean it essentially used water tanks and things, but it was much more efficient than the normal house. Oh, there also were doctors. There was a mental hospital, Powick, which has just closed I think – this is a long time after – and we found that their children were going to the same schools as our kids so we got to know the parents through various things, and again there were social events where you would find people from the three sets; the schools and the Establishment and the hospitals and my boss, David Parkinson, I think I’ve said, made a point of asking the psychos whether they were proper doctors like he was or just called
themselves doctors, because he would always make a point they didn’t have PhDs, which they
don’t have of course, they aren’t actually doctors. They call themselves GPs more now, but very
few of them have a doctorate. So that was the social life, it was, I think most people were quite
happy, content, yeah.

What’s family life like for the Hilsums?

What was it like?

[32:55]

Mm. Apart from arguments with head teachers!

It was pretty good really. I mean Betty had settled down and she was very interested in Malvern
College and had made progress there. I still think that if it hadn’t been for me, she would have
been a headmistress somewhere, she had a great deal of talent and could get on extremely well
with people. I mean she always could see the better side of people, which was more than I could.
But she would always make excuses for people’s behaviour. I think there was only once that in
all the time we were together that she really got critical of somebody that she… something to do
with the school where she said something which showed that she just couldn’t stand somebody.
And I said I’ve never heard you say that, and she said well there’s never been anyone like her. It
was some committee that she was on. And the kids seemed all right. Lin set up her anti – she
wrote to the paper complaining about the litter that was around in Malvern and said she was
forming an Anti-Litter League in Malvern. And she got two girls who came and knocked on the
door and said they wanted to join, so this was her Anti-Litter League and they went around
picking up pieces of paper, and then she discovered that she was now the secretary of the Anti-
Litter League officially from the council. And in the council documents and the things that they
put out, there was Anti-Litter League secretary, Miss L Hilsum. And she was invited to things as
the secretary of the Anti-Litter League. Occasionally I remind her of this. She doesn’t want it to
be remembered because I think these two girls only came once and then it all vanished. Karen
was very happy, very successful at the girls’ grammar school and she wasn’t rebellious, she just
progressed.

What sort of father do you think you were?
Erm, that’s a very difficult thing to say, you’ll have to ask Lin. Lin… well, the book says that I gave her support all the time. I supported them generally. It was, there always is a slight problem in this business of control and trust and I don’t think I always got the balance absolutely right, but I think I certainly got it nearer right than some other parents because I remember that I would take Lin in the car to places and she said would you take so-and-so there. I said, ‘Well, yeah, I don’t know them though’. She said, ‘Well I know her, she’s older than me but her parents don’t let her out’. So I said, ‘Well, why should they let her out with me then?’ And they said, ‘Oh, because of your position in the Establishment’. I said, ‘What’s that got to do with my character?’ And they said, that’s the way they are, that you’re trusted because you’re a senior person in the Establishment, but they won’t let her out on her own even though she’s eighteen. And I thought this is absolutely ridiculous, and I obviously took Lin and the charming girl, her parents seemed perfectly all right, and took her to the dance or whatever they were going to, and met them and brought them home and it was all right. But Lin told me about a year later that the girl had left home, which didn’t surprise me. I mean, what do you do? I mean you cannot really constrain eighteen year olds in that way. It was slightly difficult in Malvern then because there was a drug scene a bit, but fortunately ours seemed able to cope with it.

[37:10]

A follow-up question to this was, what do you think that your children thought that you did at work?

Well, Karen knew more what I did than Lin did because if Karen had problems at Cambridge, I mean she would come home now and again and would be writing up some of the things and she’d ask me questions and I would say, ‘Well, how does your spectrometer work?’ I mean she was doing some work with infrared spectrometers, which obviously I knew. And I’d say, ‘Well, what’s the scattering in the spectrometer?’ And she’d say, ‘I don’t know, it’s a box’. I’d say, ‘It isn’t a box, what do you mean it’s a box?’ She said, ‘Well there’s a slit there and there’s a meter that comes out there and you put your sample there and that’s it’. I said, ‘It’s not’. So I would try and explain to her how the spectrometer worked and what were the features in it and things like that. So she knew that I knew what she was doing and she had some idea of what I was doing, particularly later on because our work started getting quite a lot of publicity and of course, I mean it even reached the Margaret Thatcher level. So I think they had an idea of what I was doing, but it’s difficult enough to explain to you what I’m doing in detail. I mean how do you explain what a liquid crystal is and how you’re doing it, to kids. I don’t know, you’ll have to ask them. We
had a pretty, I think we were all right, we had very few quarrels and things, everything… I mean I don’t think we always agreed on what was happening and I’m sure there were times when I was impatient with them and they were impatient with me and that’s part of growing up, but I would say they were pretty happy and when we moved to London we obviously got closer to them again when they were grown up and we’ve always been in touch. In fact, I’m a little bit surprised that Lin hasn’t rung this weekend and I’ll ring her, because normally she rings me. But of course I can, it’s an unusual arrangement in that as often as not I can put the television on and can hear her.

Shall we call it a day as it’s getting on. Thank you very much.

[end of Track 20]
[Track 21]

You said I was paid for by industry and the government, that’s not correct, I was paid for by the Department of Industry and the Ministry of Defence. In other words, I was paid by two different parts of government, but I was never paid by industry at that stage.

So the MoD and industry is short for Department of Industry?

Industry, yeah.

Right, okay.

Okay. So we – okay? We get to this curious stage, which I didn’t fully appreciate, was when I was essentially reducing my output on semiconductors, semiconductor research, and when I look at the papers that I produced - this is quite a good way of looking at your record – I found I was coming down in publications from five or six a year to one a year. In ’73, ’74, ’75, ’76 there were two, but essentially, and this was accompanied by an obvious increase in the number of papers on displays, but also by reviews and things. Because curiously enough, at the time that my output on semiconductors was being reduced, my reputation seems to have been increased, which is rather curious. I was now being viewed much more as a senior semiconductor figure and of course displays hadn’t got going, so nobody knew really in the mainstream of research in the UK about display research, it was quite different. They knew about LEDs and semiconductors, but as far as semiconductors was concerned I was doing very little but was appreciated more. Which is curious and indeed, from 1972 to ’81 I was chairman of the IUPAP Semiconductor Commission. It’s a job that you’re supposed to do for three years but in fact I got re-elected to it, probably largely because nobody else wanted to do it.

What’s IUPAP, sorry?

International Union of Pure and Applied Physics. This is a very large international organisation. The International Union handles all sciences basically, I know there’s one in chemistry, Pure – IUPAC, Pure and Applied Chemistry – but there’s one, IUPAP that does pure and applied physics, covers all aspects and it has a variety of commissions – I think Commission 8 or something was semiconductors – and I was the UK representative on that fairly early on, probably 1968. But
then from ’72 to ’81 I was chairman and strangely enough, I was doing no semiconductor research, or hardly any worth talking about. And moreover, in 1978 we had the biennial Semiconductor Conference, the International Conference on the Physics of Semiconductors, which doesn’t happen very often. The previous one had been in Exeter in 1962, that was the first one I attended. And there’d have been a stream of them coming after that, but in ’78 the UK had succeeded in making a bid for it to hold it in Edinburgh and I was secretary and really organising it and Nevill Mott, a name I’m sure you can conjure with, the Nobel Prize winner and a remarkable figure in semiconductor physics in the UK and the world, he was chairman. But the organisation was up to me and this was at a time when I really wasn’t working on semiconductors, so indeed, it shows how history does follow you because when I look at the awards I got, the first one was in 1978 and that was for gallium arsenide, from the Gallium Arsenide Conference and for leadership in semiconductor research. And… things come late. And later on I’m sure that quite a lot of the reputation I gained was on the early work I’d done on semiconductors, though now I had moved to displays. And of course the group was still working on semiconductors and leaned on me slightly, but I can’t pretend that I was making major contributions. At the same time I was working on displays and obviously taking part in the research on displays, I was also [05:35] in the way in which exploitation happened. I became more interested in the whole process, which is how do you justify research and how do you ensure that what happens in your research turns into products. And of course, that was essentially what was happening with us in liquid crystals, and indeed we now, by 1978 had got the basis for all that we needed for a complex picture forming display and quite a lot of what we were doing was working out how we actually could make thin film transistors, improving the thin film transistors, putting them on displays and persuading people that this was the way forward. It is very easy to stand back and say, well this is the way forward, but of course it does involve quite a lot of funding and people have different ideas on how they want to go ahead and in particular what they can control. For instance, though we were quite sure that the switching element that you have on displays should be a transistor and really the only way forward was amorphous silicon, we still had a remnant of people who were convinced that cadmium sulphide or cadmium selenide was much easier to put down and was a better semiconductor. And there was some justification in what they were saying in that cadmium sulphide or selenide was a better semiconductor than amorphous silicon in the sense of its electron mobility and the actual property of the transistor. But that neglected the fact that what you needed on a display was essentially a switch rather than a full transistor and they underestimated the opposition that you would get from trying to push any semiconductor other than silicon. In that I was possibly helped by my
experience with gallium arsenide, where I knew that gallium arsenide was a better semiconductor than silicon, but even so I and the other people, the other laboratories working on gallium arsenide, always met with this opposition, that whatever we were doing and however good our results, it was in silicon. But that of course turned entirely round when you were working with amorphous silicon because nobody seemed to worry about the fact that amorphous silicon was not the same as crystalline silicon and it had its own peculiarities and as a semiconductor was considerably worse than crystalline silicon. That didn’t seem to matter and you gradually learnt that in even these applied scientific – and I stress scientific – areas where you think logic is going to be the overriding consideration, emotion often takes over, even in industry, and we had no problem in persuading large companies that amorphous silicon was the way forward, provided that we could find ways of putting it down over large areas. And we did this and succeeded and I think the people working on the cadmium compounds never quite understood that. Indeed, some of them still don’t understand it. They don’t know where they went wrong and they didn’t really go wrong, it was that the world did not want to have a poisonous material, and a poisonous material that might be a little bit unstable as well, as a key feature in the investment of considerable funds, so that was the way it worked. But it did take a long time and we can’t pretend that the actual display that liquid crystal gave you was that perfect a picture. The actual angle of view was quite limited, particularly vertically, and the colour rendering depended very much on the lighting that you had. But the life was good and you could actually get the effects you wanted relatively easily, you worked off a low voltage. It’s true it was rather slow, it was just about fast enough for television, unless it was very cold, because one of the points is with a liquid crystal that the response time gets longer as the device gets colder. But you don’t usually watch television out of doors, though there were later many applications for very large outdoor displays, but of course in those circumstances you can actually heat the display. So it was progress, but it wasn’t that rapid a progress. What was developing were certainly large markets in watches, in calculators, in numeric displays, and then gradually in more complex displays, particularly for laptops. [11:50] Indeed, there was a great need for simple displays for laptops. If you think about it, a laptop is quite a large display and quite a complex display and yet you want to run it off a battery, a local battery. You can clearly charge up the battery and you can have it running from the mains, but I don’t think there was anybody that sold a laptop that didn’t have one way of operating without being connected to the mains, everybody wanted a laptop that they could actually take away from the power supply and use while they were travelling or in the office without being connected to the mains. And indeed, this was of course the gap that our super twist display, that I’ve mentioned earlier, filled and filled for quite a few years, which is how we got a
lot of royalties. But we knew that this was not going to be the final way forward, that we had to push the amorphous silicon switching element, because that would give us much more complex displays and in particular picture forming displays. So we could see the way forward quite clearly, though it was a bit distressing that we couldn’t see the way forward using UK companies. We had of course the ‘UK’ company, in inverted commas, at Poole that was owned by Merck, but Merck as a very sensible German company realised that they should not remove production from Poole – at that time, they have done now mostly, but that’s many, many years later. But they developed their own materials in parallel in Darmstadt and there were very good relationships between us in the Ministry of Defence and the Merck management, very good relationships. And we carried on with them pushing our liquid crystals, basically, all over the world, particularly in Japan at that time, Korea hadn’t got the prominence it has now, and of course the liquid crystal materials that we developed were basically used for the whole life of the patents and beyond, even though other people were trying hard to develop alternatives. And I think that you can still see the roots of the present displays in the liquid crystal work that was done at Hull and Malvern in those days. Meanwhile, we were naturally trying to improve the appearance of the liquid crystal and looking for other ways of using it. We weren’t content with what was happening, we were live to lots and lots of possibilities and lots of alternative applications, because liquid crystals are electro-optic materials and there were in principle a number of applications, though most of those were liable to fall by the wayside because of the slow response in general for electro-optic devices. You would like response times of the order of microseconds, whereas liquid crystals were milliseconds. But we found other applications and other ways of doing it. We were constantly looking for memory in displays and for different ways of using them, so there was plenty of research to be done as well as the promulgation of the things that we had done in ensuring that they were followed up. So that was how the late 1970s and early eighties proceeded.

[16:15]
I was interested that you mentioned laptop displays – was that something that was actually thought about late in the 1970s when personal computers themselves are still pretty new?

Yes. Short answer is, yes. It does go back then. We obviously had moved from huge computers, and you will have covered this yourself in your own historical research, from huge computers when the IBM President said that you only need three for the nation, to the idea that lots of people would have computers and you had these strange developments of Sinclair ZX computers.
and punched tape inputs and the computers were developing quite rapidly but laptops were coming out in the late 1970s. And the display was a real problem for them. It’s very difficult to marry the two things together – the convenience of the laptop with the need for portable power. And though we could have light emitting displays, and we were developing, I should say, zinc sulphide panels that were light emitting, their efficiency was still very low. There is always a problem and still is a problem with light emission from a solid in that you can get light into a panel relatively easily, but you can’t always get light out because if the light is coming out at an angle to the surface it may get totally internally reflected and doesn’t emerge, so your external efficiency stays low and you can only improve that by shaping the surface, which is not always possible and that still is a problem and indeed it’s a problem which people working on polymer and organic light emitting displays still has to overcome. So yes, this was happening in the early 1980s. By now, clearly my interest in semiconductors had got a bit less, though of course amorphous silicon is a semiconductor. But our vision was of a display which actually had its own electronics on it. We thought of this as electronic paper, quite early electronic paper, and indeed I had a contact, which I don’t think I have mentioned earlier, with Robert Maxwell, who wanted an electronic book and we’d also thought of electronic books, but in a different way. He had thought that it was very expensive to reprint legal books – this was one of the things that his company, Pergamon Press did – and his argument was that you produce quite a thick book on law and then Parliament passes an Act and it changes the law and that clearly is going to affect part of your book. But it’s only going to affect a small part of your book and you don’t really want to reprint it or do pages, but if you had an electronic book you just could change a paragraph or a page or even a chapter. And I went to see him and at that stage of course he did not have the reputation he gained later, I hasten to say. And he was very reasonable and said, well I’ll give you money to develop this. But his idea of money was £40,000 and I said it was at least an order of magnitude wrong, if not two orders of magnitude wrong. But it was going to take a long time, and obviously it did. It took twenty-odd years, didn’t it, and saw him out for other reasons. But the fact remains, he did have the concept. But what we had in mind was a display which had the switching elements for the pixels on the display but had around the display the electronics for doing all the addressing which you normally did by putting chips on to the glass, and we thought that it would be better if you simply prepared the whole thing with thin film transistors doing this, because the actual performance of the chips was not remarkable. Now you didn’t want chips that worked faster than a microsecond, that a microsecond speed would be perfectly adequate, maybe even less, but what you wanted was something better than amorphous silicon and we thought that [21:50] what we really ought to do was work on polycrystalline silicon. Now if you deposit
silicon from a vapour you can actually get it to put down very tiny crystals and the properties that that has are intermediate between amorphous silicon and crystalline silicon and they probably would be good enough, but we didn’t quite know how to do it, though we thought it was a good research plan and we had it at the back of our mind. And then we decided to do this really as a civil programme helped by Kenneth Baker and John Noyes who we’ve mentioned before, and get some of the UK companies doing research supported under some of the government schemes which were now coming out to help people develop technology. And one of the companies that we were going to work with was Racal. Racal of course was a big company, later it developed Vodaphone which broke off, but it was very progressive. A man called Keith Thrower was receptive and we thought that this would be a good way of developing liquid crystals to actually go to the next step. We could see that what we had done with amorphous silicon and our liquid crystal was being taken up by Japanese companies and already we could see small televisions coming on to the market and those increasing in size and there was a healthy increase in the production of liquid crystals, which pleased Merck at Poole, and we could see that there was hope that the next step was going to be a display that had all of the circuitry deposited on it. So, that was the way that we could see going forward and this was now the early eighties. [24:25] And though things were going very well, there was really no problem, I received an offer from GEC to come and join them as Chief Scientist with the possibility of becoming Director of Research. Now previously I’d never made any decision at all on my life. If you think about it, in 1945 I’d been denied a decision, I wasn’t even given the choice of whether I would work in industry or for government service. The way forward, I had received offers from academia to go to various places, take a Chair or even something more senior, but there was nothing very tempting and any time there was some indication that I was getting a bit restive, someone would promote me. Finally of course as a Chief Scientific Officer, I mean I couldn’t really go much further, but now I got this offer and I think it was in ’82, first of all, that Derek Roberts who then had moved to GEC said would I like to come and join them, and in his words, ‘See what life was like on the other side’. And I asked what he meant by that and he said that more or less you have criticised us for our performance and really given us a rough time in all our contracts, now perhaps you should come on the other side and see what it’s like. Well that sounded reasonable. I was then fifty-six I think when the offer first came. Also, personally it was attractive for us to move. This was because both of our daughters had moved now to the London area and though we did see them it was obvious that it would be easier for us to see them if we were more local and of course Betty was quite keen on us doing that, and GEC made it very easy for us to actually move, we began to realise that the Civil Service was always fairly limited in what it could offer people,
whereas industry was much easier in offering you help in buying a new house and you would get a car thrown in and you’d get an increase in wages and you’d get health insurance and all kinds of things, which in the Civil Service you never dreamed of. So that was quite tempting, but perhaps more tempting was the idea of starting again with a new group and it was made clear to me that what they wanted was for me to push displays in GEC, and not just displays, but to follow other things and to form what they said was the Chief Scientist Laboratory. And one of the things Derek Roberts was quite keen on was to have a laboratory which attracted a fair number of female scientists, with the aim that we would have roughly half women and half men in the group.

Why?

Which was… quite early in that kind of initiative. And I thought that was all right, we had a few women in our group – I’ve mentioned Jenny Welborn, but also we had others who had now joined us, particularly Frances Saunders who I recruited from British Leyland to come and join us, and she was very active, a very good scientist and indeed, she later became the Chief Executive of the Defence Scientific Laboratories, so she can’t have been that bad. So yes, this was an interesting topic and I put it to the system, who seemed quite upset. They really didn’t want me to go and I said, ‘Well, I’m going to go fairly soon aren’t I, because I’m now fifty-six and you retire at sixty in the Civil Service’, and they said, ‘Oh no you don’t, no you don’t, you’re an individual merit’. I said, ‘Yes’, and they said, ‘You don’t have to retire. You carry on in your same rank as long as you like’. I said, ‘What, seventy, eighty?’ They said, ‘Yes, yes, no problem’. And they did point to a man I knew, Dr Sayce, who’d worked in the optics labs and I did know him, he was a very good scientist, they said he went on till his mid eighties, so you can stay on. I said, ‘Oh, well that’s interesting, I’ll have to think about that’. And they said, ‘Of course’, I said, ‘Well, what’s the formalities?’ They said, ‘All you have to do is to actually each year write us a report on what you’ve accomplished in the year’. And I said, ‘Well, who do I send it to?’ And they said, ‘Well, you… [telephone ringing]

[pause in recording – 30:24]

Okay? You have to produce a report. And I said, ‘Well, who does it go to?’ They said, ‘It goes to headquarters’. I said, ‘And what?’ And they said, ‘Well somebody sort of looks at it and says, oh, yeah, you can go on’. I said, ‘Well what if they don’t, I said who looks at it?’ They said,
‘Well some civil servant’. I said, ‘So my life is in the hands of a civil servant that I don’t know’. And they said, ‘Well, I suppose so’. So I talked it over with Betty and we thought that wasn’t really a good idea. It seemed more interesting to go to GEC and also to move to London. So we said no, I’m going to go to GEC, I’ll keep in contact obviously, but I’ll go to GEC. And I could keep in contact with the Ministry of Defence later on by continuing work with the Defence Scientific Advisory Council, though from, be from the other side because I was secretary of some of the committees then and I’d moved eventually to the other side. There has to be a period of one year there. In fact I could only move if there was no serious objection from industry, UK industry, to my moving because in principle I knew something of what they were doing, fairly obviously. Ferranti’s wasn’t happy, but the system said they had no reason to be unhappy.

Why were…

Philip’s… mm?

Why were they unhappy?

Well, they didn’t like the idea of my moving to GEC, they presumably thought it gave GEC an advantage, I don’t know. But I’d not done anything, I had not had any formal connection with Ferranti’s for some years. I’d had some connection with, probably ten years earlier when they started on silicon, but I don’t remember having much of a connection afterwards with them. They may, I don’t think they got into gallium arsenide. But anyway. Philip’s had an objection: they said they didn’t mind my moving as long as I didn’t work on infrared for the first year, and I pointed out that the only time I’d worked on infrared had been about four years earlier when I had been Deputy Director for one year. But I said that was all right, I had no intention of working in infrared. In fact it was a very nice compliment so I wrote a letter thanking them, because I thought that was really a nice comment on my abilities, that I could do something after all the period of being away that would interfere with them. I think it was a ritual objection rather than anything else. So the system put in a delay, my going, so I didn’t move until I was actually fifty-seven. [33:45] But I moved to London, to Wembley and that was a change. Do you want to stop there and…

I’ve got a bunch of questions we should probably wrap up before you have left the Civil Service.
Okay.

I was thinking, all the things you’ve described about going to join GEC all seem to have been attractions. I was wondering, you know, there were lots of pull factors taking you that way, are there any push factors?

Well, of course there were push factors in the sense I was leaving two groups, effectively, that I’d worked with for many years and the people were there. I had developed two strands; one on displays and I hadn’t completely given up semiconductors, I still knew what was going on. I mean clearly they had moved on, but they’d moved on in the directions that I had really started. The work on hot electrons was still going on but it had diminished and some of those people were leaving too, so it wasn’t a static situation in that sense, and of course locally we had many contacts. Betty was still now second mistress at Malvern Girls’ College, so that was going to be a pull for her to go. We’d settled into a house and a garden. Indeed, our original idea was that we would not move, completely, that we would take a flat or something in London and stay there in the week and keep our house in Malvern where we’d come back at weekends, and that’s what we did for a time until it became obvious that we were getting the worst of both worlds, that we neither had a social life in Malvern nor in London. When we came back to London we were spending most of time mowing the lawn and cleaning the house and things and generally sort of putting things straight before we came back to London. And in London we couldn’t really settle and didn’t have a social life either, so that only lasted for about six months. And quite apart from that, I had developed responsibilities within MoD generally as, well their senior working scientist. I was handling promotion boards and generally was looked at for research guidance. I was also giving lectures on research management to the Civil Service, so yes, there were a number of things which were holding me back. But it was about time I made a decision on my life. But the main thing was, well the two main things. One was moving to be nearer the children, our two daughters and their families that were developing, and the other was really to go on beyond sixty in a more permanent fashion than the Civil Service offered. The Civil Service were very good in what they were offering, there was no animosity at all, it was just that they did want me to stay. So yeah, that was flattering. But still, and I knew that I wasn’t cutting myself off, it wasn’t that I was going to do totally different lines of research, though in fact some of them that developed were quite different, as will become clear later on.

[37:45]
I was interested as well in the fact that you did become more or less the top scientist in the MoD, aside from headquarters than, did you say Deputy Director of Malvern?

Yes, that was an aberration. I had naturally avoided administrative posts since I was in my early thirties and I had progressed up the ladder until I now was at the top, which was effectively a rank equal to director of a small laboratory or deputy director of a large one. And Malvern was very easy, as was Ministry of Defence, there was no problem in handling this, that I would be treated as a scientist and not as administrator, but that didn’t mean to say I wasn’t being given administrative jobs. As I said, I was handling the PSO promotion boards and handling the competition for research funding with the laboratories generally and nobody saw any problem in this. It was a curious situation, I suppose you can say, in that the division was handled by a Senior Principal Scientific Officer and in his staff he had somebody who was two grades higher than him. But we managed. We divided responsibilities. You weren’t divorced from administrative responsibilities in the sense that you still handled the promotion prospects and the career progression of the people who had chosen to align themselves with you, but that was much more voluntary in what the people did. The standard Civil Service system is that an assessment is done each year - was done, I don’t know what happens now – each year of all staff and that is done by their senior line manager and they come to an agreement on how that is filled up, right. And then they’re entitled to an interview on that with the line manager’s line manager and though in principle that should have been the division leader, in practice it was me that they came to, so I handled that. Not always to someone’s satisfaction. Sometimes they would have done better if they’d gone to the proper line manager instead of me, but most of them seemed to want to actually talk to me. I suppose I was pretty busy with general things and they appreciated the opportunity of an hour really where I was theirs and they could grumble and talk to me. And it was curiously productive. I can give you one example of somebody who came to me, he wasn’t a very senior rank but he was entitled to come to me, he’d had his interview and he was quite happy with that but he wanted to talk to me. And he came in and produced a very large sheet of paper which he unrolled for me, and this was obviously a calendar for the year. And I looked at this and said, ‘What is it John?’ And he said, ‘Well, I thought you’d be interested in knowing my plan for the year’. I said, ‘Yes, yes I am. Well, go through it with me’. So he said, ‘Well, this is where we start at the beginning of the year and this shows what I’m planning to do during the year’. I looked down, I said, ‘Well that’s very impressive John, that’s very impressive’. I said, ‘But what happens if you invent something?’ And he said, ‘Invent something?’ I said, ‘Yes’ I said, ‘That’s the business we’re in aren’t we?’ He said, ‘Well yes, I suppose so’. I said, ‘So what
happens if you invent something?’ And he said, ‘Well, I’d have to take note of it wouldn’t I?’ I said, ‘Yes, you certainly would have to’. He said, ‘Hm’ he said, ‘Well it depends when in the year I invented it doesn’t it?’ I said, ‘Well, let’s say you invent something sort of halfway through the year’. He said, ‘Yes, yes let’s say that, yes. Hm’. He said, ‘Well’ he said, ‘I’d have to alter what I’ve got in the second half of the year wouldn’t I?’ I said, ‘Yes, you certainly would’. He said, ‘Yes, I’d have to alter this sheet wouldn’t I?’ I said, ‘Yes’ I said, ‘Would you look forward to that?’ He said, ‘Look forward to it? Well, inventing something, yes I’d look forward to it, yes’ he said, ‘But I’d have to alter the sheet wouldn’t I?’ I said, ‘Yes John, you’d have to alter the sheet’. He said, ‘Hm, don’t know if I’d like that’. I said, ‘What do you mean, you don’t know if you’d like that’. He said, ‘Well, I’ve put in a lot of work on this sheet haven’t I?’ I said, ‘Yes, you certainly have, it’s a work of art’. He said, ‘No, no, I don’t think I would look forward to that’. I said, ‘So basically you wouldn’t be terribly pleased if you invented something, you’d sort of on the one hand be satisfied but you’d feel it was upsetting your plans?’ He said, ‘Yes, yes’. So, at the end of the hour we were both convinced that he wasn’t cut out for research at all, but he was a damn good support to people and we concluded that he should now concentrate on supporting people, that he should actually wander through the group. He was an excellent electronics expert, and he should walk through and generally find places where people needed some support and help them. And it was ideal. I mean he was very happy, they were very happy, he no longer had the pressure on him to actually sort of act as the other people did, he was a different kind of person. So, that’s an anecdote for you and I remember it, very interesting time. And I can say that I had no idea when he came into the room what the hell this large roll of paper was that he had presented me with. So, that was the way it went, but I don’t know that other organisations would do it, but it did lead to some very strange situations when we went abroad and things with people from other laboratories where essentially I was the senior person, though they were perhaps running five or six hundred people. [45:30] Anyway, one day I was summoned to, I think it was Andy Smart’s office and he said, ‘We’ve got a problem Cyril’. I said, ‘What’s the problem?’ He said, ‘Well as you know Stan’s retiring and there’s a vacancy for Deputy Director?’. And I said, ‘Yes, well we’ve met that problem before, so who’s going to do it?’ They said, ‘Well, there’s only one real candidate’. I said, ‘Yes, who’s that?’, so they mentioned a name. I said, ‘Don’t talk… that’s ridiculous’ I said, ‘He used to work for me years ago, he couldn’t possibly be Deputy Director’. They said, ‘Well, we’ve got reservations but he’s the next one in line’. I said, ‘Well, I mean it’s not possible, you can’t do that’. They said, ‘Well, we are a bit worried, but the only other person who could do it is you’. And I said, ‘Look, no, I’m a scientist, I’m not going to run half the lab’. And they said, ‘Well, there isn’t anyone else’. I
said, ‘What about so-and-so?’ They said, ‘He’s too young. He’s too young’. I said, ‘I don’t think he’s too young, what do you mean? He’s forty-ish’. They said, ‘No, he’s too young, too inexperienced’. Now I was alert to this situation that I was being forced into, a situation I did not want to be. I said, ‘How much too young is he?’ They said, ‘Oh, he’s two years too young’. I said, ‘How about one year too young?’ They said, ‘What do you mean, one year too young?’ I said, ‘Well, if it was one year, and a definite one year then I suppose I could do it, but one year’. And they thought and said, ‘Well, he could go to the Staff College immediately, and be trained in management and that would be one year, so probably that would be something we could put to headquarters, do that’. So that was agreed, that I would do the job for one year and then this other person would go to the staff college and come back and take over after one year. So I agreed, I immediately summoned the three department heads that I was supposed to be responsible for and said, ‘This is bad news, you’re going to be reporting to me for a year’. They said, ‘Oh my God’. And I said, ‘And I don’t want to hear anything from you, as far as I’m concerned you are running your departments, everyone will be happy with what you’re doing, I do not wish to know what is going on unless there’s a crisis and if there is a crisis then you will be in trouble’. And that’s more or less how we managed it. They ran their shop, I did the minimum that I needed to do as Deputy Director, there were a few things I had to do like attending board meetings every month and I suppose I had to – oh, I did, [48:50] one of the things I had to do was to close SERL, which I have mentioned before. I discovered sort of in the middle of all this, nobody had told me this, somebody came and told me, ‘What are you planning to do about Baldock?’ I said, ‘Baldock? I wasn’t planning to do anything about Baldock. They’ve moved all the staff here, I mean they’re sort of all over in Q Building or something aren’t they?’ They said, ‘Yes. But we still have an establishment at Baldock’. I said, ‘Well, there isn’t anyone there’. And they said, ‘Well the police are still there’. I said, ‘You mean we’ve still got police guarding an empty site?’ They said, ‘Yes, we’ve got to, I mean it’s a site, we have to have a minimum presence there’. I said, ‘Well, why don’t we close it?’ They said, ‘We should’. I said, ‘Well, why haven’t we?’ They said, ‘Because nobody’s been willing to sign the form that officially closes it and starts the procedure for closing it’. I said, ‘Well, give me the form and I’ll sign it’. So they gave me the form and I signed it and that’s when I realised why nobody had been willing to close it before, because before it could be closed and essentially sold, there had to be certification that it was safe and had been… and it wasn’t safe. We had in my time, which I suppose was fifteen, twenty years earlier, twenty years earlier, been working with gallium arsenide and when we checked we discovered that there was arsenic in all of the soakaways and things and there shouldn’t have been. As far as we were concerned we had fume cupboards and
things which had been designed to the highest standards and indeed had porcelain soakaways from running, well soakaway drains from the fume cupboards so acids hadn’t affected them at all. But when they looked into it to find out where this arsenic had come from, they discovered that the people twenty years earlier had actually designed the fume cupboards with a one foot porcelain drain and then it had gone into a lead pipe which went to the soakaway and it hadn’t occurred to them that the acids that were being used would of course eat away at the lead pipe, so the drain was full of arsenic. And there was a threat, which clearly had been in the minds of the people before they closed the lab, that this had gone into the local area and might have poisoned the local water supply. So we had to look into it and check what had happened, and fortunately, and I can’t say that anybody had designed this or had thought about it, we discovered that in fact that nature took care of it, that the arsenic content from the soakaways decreased very rapidly with distance and it couldn’t be detected even as far as the boundary of the establishment. So although it wasn’t very sound there and it needed quite a lot of work to get rid of the threat, at least it was local, it hadn’t gone far, so we were able to actually get rid of it and I could close the establishment. And I think that was my major achievement. [53:09] I did some other things, we discovered that there was in fact a – the main things I got concerned with were health and safety rather than science when I think about it. We discovered that the building that had been erected by a very distinguished architect to handle the gallium arsenide production, which gallium arsenide was now by now quite a standard material that was being used for defence applications. It had come on a great deal in the ten years since I had given up work on it, and we had a group in a new building that was doing gallium arsenide circuitry and things and of course that had to have a system for getting rid of the arsenic vapours on this and there was quite a nice chimney that had been erected on the roof of the building and we were a bit concerned, and it was reported to me that although we had this chimney there some people were thinking they could smell some fumes. So I went up with the man who was in charge and went up to the roof to look at this and discovered that – we went up at lunchtime, that’s right – and discovered there was a man sort of sitting on the roof in a deckchair eating his lunch. We hadn’t known, but there was no particular rule why he shouldn’t be there and we said, ‘Hello, we’ve come up to look at the fumes’. He said, ‘Oh yes’ he said, ‘I come up most days’ he said. ‘Get a funny smell some days.’ We said, ‘You do?’ He said, ‘Yeah, yeah, get a funny smell from that fume thing’. And it was the chimney that went up. So we got some surveys done and discovered that the fumes did leave at the top, but then they crept down the side to the roof and went over the side. We did not broadcast that and we had to modify the fume cupboard inside, I mean it hadn’t been designed properly. So this was the kind of thing that occupied me, I can’t say that I really had a lot to do with research
progress in the rest of the establishment, [55:40] though clearly I had to do more administration than I had planned.

\textit{Why was Baldock being closed at all?}

Oh, this was the combination of the establishments. This was at the time of rationalisation. Essentially the Ministry had three laboratories that were working in similar areas, they weren’t working on… there wasn’t a lot of overlap in the sense of the research programme, but the mandate was quite similar, that Baldock was an inter-service laboratory that worked for all three services but it had tended to do much more applied stuff and its research had decreased. I mentioned earlier the explosion of staff that Sutton had caused with all the senior people leaving and they’d never been able to make that up. They’d done some quite reasonable research but it had made no impact at all and it was tending to do very applied things and it was linked with research going on at Malvern. There was also the army establishment at Christchurch, the Signals Research and Development Laboratory, which had a very good reputation for doing work for the army. They had taken over the infrared responsibility from me back in the 1960s when I had asked to be relieved of it, it had gone there and it was a much more natural place for them to do it. But it was another laboratory and so the Ministry of Defence had basically three electronics laboratories that were doing electronics research rather than electronics systems. They had other establishments of course. They had the Surface Weapons Establishment at Portsdown, which was really an Admiralty establishment, for doing surface weapons – surface… Essentially Malvern, the systems part would be doing systems for the Air Force. And then they had the Admiralty Underwater Weapons Establishment down at Weymouth and Portland, which was doing torpedo research. So it was decided in a rationalisation that SRDE at Christchurch and SERL at Baldock should all be united on the Malvern site, or at least on the Malvern sites, because not everything at Malvern was being done in Malvern. And there was satellite research – Malvern wasn’t really suitable for really satellite communications, you needed to be further away from the hills and we had an airfield at – forget the name – about ten miles away, which had a very open area and that would be very suitable for satellite communications. We had some empty laboratories in north Malvern, dating really from the war. So there was a reasonable amount of space and the actual Malvern site was not completely full. So it was decided that all three should be united at Malvern in ’76. Indeed, the picture that I showed you of the Queen laughing was done when she changed the name of our establishment from the Royal Radar Establishment to the Royal Signals and Radar Establishment. And that was done for lunch in March ’76. So the Baldock staff gradually
moved [1:00:15] and most of them did move, a few of them didn’t, but most of them moved. Christchurch was different. Baldock was okay but it wasn’t an ideal place for families to live, in the sense it was a long way from a big town or the sea or anything. Christchurch, on the other hand, was a most attractive site. It was in the Bournemouth area and people had beautiful houses, they had boats and kinds of nice living as well as it being a very good establishment. So there was much more opposition to people moving, and you can understand that, that the establishment was going to be closed but a fair number of staff, I don’t know what the percentage was, I suspect it probably was as high as twenty-five per cent, did not move, they just left their jobs and took local jobs and stayed in Christchurch or the surroundings, as far as I know, still do. So yes, that all happened but it had happened before I had to cope with it at all, I was just dealing with the aftermath.

What was the rationalisation you mentioned a few times?

That rationalisation has continued to this day, that the government did want, did not want to have a lot of establishments and the responsibility for the land, they could sell off the land and generally reduce their commitments. This has continued to actually saying they don’t really want much responsibility for scientists, if you actually look at the number of scientists who were employed by the government back in the 1970s you’ll probably find that four or five times as many as they have now. You have, the Ministry of Defence has got rid of a lot of their establishments by first of all forming the Defence Research Agency, which became the Defence Electronics – I think it’s Defence Electronics Research Agency – it was called DERA anyway, which then was essentially bought by QinetiQ which took over most of the staff. I think there were probably about four times as many went to QinetiQ as stayed. The defence staff were restricted to those who were essentially doing anti-terrorist research down at Sevenoaks and the chemical and biological warfare people at Portsdown, and then people who did more integration. That’s essentially a word used for taking the results of research and putting them into the design of military systems, which of course involves also the contracts for the original research. But QinetiQ inherited the research people mostly and the rest formed what’s called DSTL, which I mentioned earlier that Frances was CEO of, and that has completely evacuated Malvern, has some people, about a thousand I think, maybe slightly less, in Portsdown and the rest are in Porton. There may be, I don’t think there are any still in Farnborough. There may be, I don’t think so though. I think it’s just Sevenoaks, Portsdown and Porton and I think QinetiQ really runs Farnborough and some smaller establishments now.
As someone who’s part of this organisation as it was in the late 1970s, how did you feel about being someone who’s part of something that is being rationalised?

Terrible.

Sorry?

Terrible. I thought it was essentially a way in which what I and many colleagues had established as an inheritance was being passed to a company that had no history of involvement and where people would be making millions of pounds out of what we had really set a foundation for. And you will find that there are many people who feel like that, that QinetiQ essentially profited. And the people came in and they may have done a reasonable job in doing it, but we always thought that it had been sold to QinetiQ on the cheap. Industry did offer more money, some of the companies offered more money, but they were thought to… they would have been putting those companies in too powerful a position and it was thought that it was better to let QinetiQ take it over, but there was tremendous opposition from people who had worked for the Ministry of Defence and the number of people who came into QinetiQ at senior positions, there were some of them who had been with us, made large sums of money out of it and we thought it was wrong, that it shouldn’t have happened that way. But we could see it happening right at the beginning, in fact a group of us quite senior people; myself, Roy Pike who was a Deputy Chief Scientific Officer, Alistair Johnson who’d been Director of Sevenoaks, tried to persuade them not to do it, to find a different way of simplifying the administration but not to actually form a Defence Research Agency, which was the beginning, we could see this as the thin end, thin end of the wedge, and that’s exactly what happened.

When abouts did you have these meetings?

This was probably in the nineties at the first, when DERA was formed, I wouldn’t be… I think that’s about right, in the nineties. Because it went through this procedure of being a Defence Research Agency where Porton was separate. Porton wasn’t touched, being chemical and biological and nobody was going to pass that. But then it was united, I think it was about a year later, it may have been slightly more, that it became DERA.
What sort of reaction did you get to your appeal?

None. [1:08:00] Water under the bridge now. Nothing you can do about it. But essentially, you’ve seen what is happening, I mean for instance last year QinetiQ decided that it was going to stop all the research done on photonics, which is the word to describe the infrared photocell work and the liquid crystal work and things, and just stop it on the grounds it wasn’t profitable. There are various stories going around that the senior people did not know that was happening and I can’t pretend that the people actually in position planned their response to this very sensibly, they thought that the government would actually back them by giving them contracts, but they had the wrong government for that. And it’s just stopped, basically, and people have left with different jobs, but there is no inheritance left there at QinetiQ at all. And QinetiQ is abandoning quite a lot of the research because they are a company and you need to be a different kind of company that is willing to continue in this kind of electronics research. I think it’s no secret that we’ve lost most of our big companies except in the pharmaceutical industry, both in electronics and chemicals, we’ve essentially lost the GECs, the Ferrantis, the Plesseys and the ICIs. And that’s essentially because the way in which we do business in the UK is not conducive to long term research, but that will come much later in our deliberations.

In a sort of big picture sense, what did you see the point of government science as?

I saw government science as taking the risk out of exploitation of research. That though… development has started to work on a much shorter timescale in the sense that you’re getting modifications to systems for consumers almost every year and indeed, when I was later at GEC and wanted to point out to somebody, a company, a smallish company but a very progressive company that wanted to make a music centre, and they wanted to make a music centre that had a display and they were negotiating with GEC for a display that we were working on, that wasn’t liquid crystals actually, it was a zinc sulphide display. And I had to point out to them in all honesty that having sort of met a price requirement that we could make this device for the price that they wanted, I said, ‘But of course you have to appreciate that this display, because it emits light competes with direct sunlight, so you won’t see it clearly if the sunlight falls on it’. And they said, ‘Well, they’ll have to put it in a darker corner of the room won’t they?’ I said, ‘Oh, oh, well. And the other thing you have to appreciate is that the life of the display is limited in the sense that its brightness gets less as time goes by’. And they said, ‘Well, what kind of life do you think we’re going to get?’ I said, ‘Something like 16,000 hours and it comes down to half
brightness, which I know is not remarkable, but that’s the best we can do at the moment’. They said, ‘16,000 hours? That’s over two years’. I said, ‘Yes, yes’. They said, ‘Well, in that time we want them to buy another one don’t we, we want them to buy another music centre. We don’t them to hang around with the same one’. And I realised that times are a-changing, because of course the point about chips and silicon and the things that we were doing with liquid crystals were getting up to 100,000 hours or more, that was our life, but now you have to deal with things going. But the point is that though the development of things goes very rapidly, research doesn’t. You often find that you are learning much more about what is happening by doing your research and it’s taking time. Now, I’m not talking about the kind of forty years that happened with magnetic tape and things and magnetic materials, I’m talking about sort of seven or eight years in doing something that is new before you do it. Typically – we will come later on to the company that I’m working with, Peratech - where essentially it started with a very simple polymer device which was an electrical switch and we’d been doing research on it and working on how to make it for eleven years before it actually sort of now looks as though it’s going to be successful and of course what we’re making now is not what we were making eleven years ago. And we’ve learnt by our research how to do it, and that’s not an unusual timeframe. But a big company is not very happy to do that with investing the money without getting a return. That’s linked with the way in which we actually judge companies and the way they do their accounts, but that again is another different story. But government intervention can reduce that risk and many companies do that and it so happens that very often that is done by having defence contracts. You may not even be making something for defence. It’s interesting that one of the most successful organisations in America is the Defense Advanced Research Products Agency, DARPA, and at one stage there was DARPA and then they decided it would do civil things so they took the ‘D’ off and called it ARPA. And after a year or two they decided this is rubbish, I mean we’re going back to calling it DARPA. So still handled by defence, [1:15:30] but it takes a very flexible approach to how you’re going to exploit research, and indeed, it says that we never know how we’re going to exploit research. When you do research it turns things out and very often you get something that you haven’t appreciated you were going to make possible and as often as not this is something you can use for defence. So DARPA is a very progressive agency in the States and it does show that you can take the risk out. You have to have an understanding with the company that if they do make something afterwards and you do want defence products to emerge, that you’re going to get benefit from it, you’re going to get them cheaper. But that’s not quite why you’re doing it, you’re taking the risk out. And that’s what we always were doing with our contracts. Now it’s, it’s more difficult. The Treasury doesn’t see things quite that way, partly I suppose because it
doesn’t have scientists working there and it doesn’t appreciate the way, the complete way in which you go from acquiring knowledge to selling a product, which is not straightforward.

_Interested on the exploitation fronts as well. I guess we’ve talked about the consortium - as its various, CVD and Hilsum consortium – performance over the last few weeks, but I was just wondering, viewed overall, how effective do you think that was as a way of exploiting the research on semiconductors you were doing?_

Well, I think you can say it’s flattered by imitation, because that’s the way in which the Commission handles all its research. The Commission does not give contracts to individual companies. It gives contracts to consortia of companies who are supposed to agree that they will share all of the knowledge, including the patents and things. And it certainly was copied in a number of the UK initiatives when DTI used to run initiatives: the Advanced Computing Initiative, the Alvey Programme – all of these were handled in that way. It was reckoned that the best way of proceeding was for companies to work together. This is not generally done in the pharmaceutical industry, which is more competitive. But in almost all research initiatives they do this now collaboratively. So yeah.

_Who are the Commission, sorry?_

Hm?

_Who are the Commission?_

The European Commission.

_Right._

If you look up the Commission and find out the way in which they do it, they… the way they do it is you have to have representatives from different countries. You can’t have a programme, a collaborative programme done entirely within one country so you have to have two or three, I think.
I guess one of the other questions I had on the semiconductor front was, we’ve spent a lot of time talking about various forms of gallium, other III-V compounds, but very little time talking about silicon, which I guess is the one semiconductor that most people know from silicon chips. Why the decision to pursue gallium work rather than silicon?

[sighs] Some of it’s historical. It was natural progression. The thing I was working on originally was an infrared photocell which you couldn’t make in silicon and my roots were infrared and you couldn’t do that with silicon. Then I carried on working in indium antimonide for its galvanomagnetic effects which were very interesting and unusual. So I was into the compound semiconductors and then I was asked to take over the work on gallium arsenide, which we had come to almost in parallel with people working on silicon. See, I saw that I have here a piece of paper which is interesting. I didn’t even realise I had it here. [pause] I probably won’t be able to find it now. [pause] See, when I came into gallium arsenide that was ’59 and you can see here how silicon was still very new. I mean in ’59 only five per cent of devices were being made in silicon and almost all of those were being made by Texas Instruments. And you can see how expensive it was. The average value was fifteen dollars nearly, per item, whereas two dollars for germanium. So it was by no means certain that silicon was ever going to make it and the only reason why people were interested in silicon was because it’s better temperature effect. Germanium has a mobility of 3,000, silicon has a mobility of 1,000 so that automatically means that if you make a device that’s geometrically the same in those two materials, the germanium will work at three times the frequency of silicon and for many applications you want a higher frequency to work things. You really, I mean if you’re going up to radar of course you want millions of millions in frequency, but you certainly want a number of millions for picture forming devices and things. It’s a question of how complex the information is that you’re trying to progress through your electronic system. So, people would have been very happy with germanium, but the trouble was that germanium did not work above 60°C. Now, 60°C may seem quite a high temperature, but you’re talking about the operating device, you’re not talking about the ambient temperature, and you have to put power into the device to make it work and you can very easily get a transistor working at a temperature which is uncomfortable to touch. And that meant that you couldn’t do it with germanium, you had to use bigger things with heat sinks to get them working. That doesn’t mean to say people didn’t use them, we did, a lot of our air traffic control was done with germanium transistors. But people could see that silicon could work up to over a 100°C. So you had this choice, what are you going to do, and in general people said well, we really want something that works at a higher temperature and we will get over the frequency
limit by making all the spacing smaller so the electrons don’t have as far to go, even though 
they’re travelling slower. And gradually you could see the reduction in germanium, but I’m not 
sure that you could even see a reduction in germanium here. No, even you see in 1965 you still 
were getting a terrific increase in germanium, though silicon was catching up. Now, you then 
were going to have silicon with a mobility of 1,000 working at a reasonable temperature and 
suddenly you could see the prospect of gallium arsenide with a mobility of 10,000. Defence 
electronics always pushes frontiers back. So it was clear that you would be able to make faster 
devices from gallium arsenide than you could from silicon. In addition there wasn’t that much 
need for defence to do silicon because industry could see clearly that semiconductor electronics 
was going to be taking over and they could see that if they could master first of all germanium 
and then silicon, then they would get products coming out. But they would never do that for 
gallium arsenide because it was too difficult a material and the prospects were too uncertain. So 
there was a need for the government labs to intervene and take away the risk. So logically the 
target was very visible in that gallium arsenide could work at even higher temperatures than 
silicon. It could also go much faster so you’d get a better range of devices. You knew you 
wouldn’t have the mass production, [1:26:15] but that didn’t matter for defence. At that time 
people were not making chips, they were making individual devices in these materials, so there 
was no problem in putting the things together. And indeed, this proved immediately successful. 
Remember, talking about 1962, we made the first microwave devices based on gallium arsenide. 
There was no possibility of making those in silicon, you couldn’t do it, it wouldn’t work. You 
couldn’t make transistors, there was no equivalent in the energy levels in silicon. So immediately 
you could see that there were two families of devices, quite separate ones. You had the light 
emitting devices, which were infrared emitters in gallium arsenide but by a slight variation you 
could get visible red light coming out. So you had these sources which were very useful, even as 
indicator lamps, with a much longer life than you could get from tungsten filament lamps, and the 
prospect of lasers as well, though we didn’t know quite how we were going to use lasers, you 
could see that there were going to be applications for them. And quite separately we had our 
microwave devices. So there was no problem in justifying the research in the absolute terms of 
what they would do for defence funding, or defence applications. So yeah, that’s the answer to 
your question.

[1:27:48]

One clarification…
Now, in addition, I mean Malvern was working on silicon research, but it had a totally – well I say totally, it’s not completely totally – they worked on germanium and silicon but they were interested in microwave applications of bulk crystals. It never came to anything but they were interested in what you might do with the microwave properties of these materials and they certainly did some work on silicon. So there was very little pressure on Baldock to actually do anything on silicon. In fact, pressure would have been the other way.

_I had one or two minor clarification questions as well. Device, I was just wondering what scale as a device – it’s a term we’ve used quite a few times, but it just occurred to me earlier, I’m not quite sure if we’re talking about things on the scale of individual transistors or entire screens or…_”

Yes, you are. Well, you’ve got complications when you start talking about chips. A transistor is a device, a photocell is a device, a microwave oscillator is a device. You normally think of an assemblage of devices making up a subsystem and a number of subsystems making a system. So some people will… you can use the word component, which is probably more accurate.

_That’s the one I’ve just jotted down as equals to, so that’s…_”

I think that’s what it is. We use the term device, you’ve got a banner with a strange device, device. You do talk about device research. I think this is a scientific jargon. People may think of an intruder alarm as being a device, we wouldn’t think of it as being a device or a… if you said device equals component, you immediately say well, an intruder alarm is not a component, it’s a system. You put an input and you get an output. What happens on the way is transmission through a device or a component and a number of subsystems.

[1:30:24]
_I have one final question as well, just to wrap up the liquid crystal display work. I guess today, you know, liquid crystal displays have become incredibly common; most TVs have them, laptop screens, large TV on the wall opposite us has them. But, you know, compared to today’s state of the art television, things we’re used to in everyday life, what was the liquid crystal display like back in, let’s say, around 1980? The stuff you were working on, what was the state of the art then?_
In comparison?

1980, well as I say, I did say that we had watches, you had a lot of watches. In fact watches came and went, that’s the interesting thing, that liquid crystal watches were sort of everything that people did, but then, now it’s quite difficult to buy one. People don’t want them. It’s curious. There were LED watches as well, they disappeared because of course you only could see the time by pressing the button, because otherwise it ran the battery down too much. But liquid crystal watches lasted for quite some time, but then they faded out. I think that they weren’t good looking enough. The kind of thing that you could do...

Shall I unplug you now?

Oh, where’s that gone? Oh, it’s there. No, I’m not going to go very far.

Oh, all right.

I’m going to go a little distance. That’s the kind of size that we would be making and not very different in its complexity.

Do you mind describing what that actually looks like for the purposes of the tape?

[laughs] It just is a liquid crystal display that shows alphanumerics. I did say that you can show a number with seven bars but you can’t do the alphabet with seven bars. You can but it looks very peculiar. But this is probably a few more than seven bars. Actually these are – one, two… well you can do some of the letters. This is a seven bar. But you will find that you can’t do – no, it’s not seven because that ‘R’ is at an angle. You progress in what you can do by the number of points that you can, the pixels that you can address. And you could not do a picture. You could do several lines of numbers and letters, you could do a message, but you couldn’t do an image. And there were obviously a whole range of things that you wanted to do as images, but you – that didn’t mean to say that… [telephone ringing]

[1:33:45 – pause]
Now what we had of course at that time, you will have some indications on that thing and you’ll see those displays.

*On the video.*

On the videos and things. And all that kind of thing you could do and there was competition between different ways of doing this, that you could do it with things called numitrons, which were gas discharge tubes, there are vacuum fluorescent tubes that you could do very well, particularly if the thing is powered from the mains. Another advantage of liquid crystals is that they use no power. I mean it’s an insulator basically, it’s just changing capacitance. So there is a very small amount of power that you use when you change the information, but it’s ideal for something that’s battery operated, like a watch or a calculator. And although some of the calculators that were made, the Sinclair calculators were using LEDs, they didn’t last for very long because the batteries give out. So there was a market developing once, once they had available a stable material. So you will not notice much of a change in the slope of increase of liquid crystal consumption, but it went, I mean it kept going, it still is going, it might have flattened off slightly during the recession, but essentially you will see it going up from 1975 probably when they started seeing and it just carried on going up with more and more products. But there was no prospect of pictures until we had the super twist display first of all and then the amorphous silicon.

*Is that because of the refresh rate then and…*

Essentially it’s a way in which you can put information on a display without ambiguity, that you can go up to probably - there is a formula which tells you what you can use, made by people called Plesh and Alco, I think his name is, but Plesh [interviewee correction: Alt and Pleshko] is certainly the first, they worked out a formula – and with a typical liquid crystal characteristic of a change in the appearance with voltage you can do something like twenty lines using a lot of picture elements to even do a message. If you want an alphanumeric you’ve really got to have thirty-five picture elements. If you want colour you’ve got to multiply that by a factor of three, so you can probably go up to about five or six lines before you start getting some variation in contrast with some elements and if you go much beyond that the information you get is confusing and can lead to errors. So there are clear limits on the amount of information you can put on the
display, that is vertically. You can just extend it horizontally okay for a bit, but that runs into other problems.

[1:37:55]

*I have one final question about liquid displays. We’ve talked quite a bit about companies like Plessey, Marconi, big established companies, but did you have much to do with the more consumer end of the spectrum, electronics – companies like Sinclair you mentioned with calculators?*

Well, I had something to do with Sinclair because part of my responsibilities was to provide new displays for defence applications and this was done through CVD and I was, I think I was chairman of the Display Devices Committee, so it was my responsibility to look at all displays, not just liquid crystals, also electro-luminescent displays, plasma panels, any kind of display – LEDs – and also cathode ray tubes. I was responsible for that kind of research and we were doing research all the time on improved phosphors, better resolution, working at lower voltages, all kinds of things people were working on. And I did for a short time get involved with Sinclair on what he claimed was a flat cathode ray tube, which wasn’t. I mean it was an angled tube which, where the electron gun was vertical instead of sticking out horizontally and there was a voltage to swing the electrons through to a screen and he claimed it was a flat cathode ray tube and I was willing to give him a contract for further development but he didn’t want a contract, he wanted a lump sum and then he would supply all the tubes on the lump sum. But he hadn’t yet produced any, so we had no confidence that he could do and that wasn’t the way we went, so we parted company as friends and said no, we don’t do that, we will pay you a research contract and at the end hopefully you can produce the things and then we’ll buy some from you. He didn’t want that. So yes, I did get involved. [1:40:20] But in liquid crystals, I mentioned Racal earlier, and Racal had a plant at Tewkesbury, which was fairly near Malvern, and they came to see us quite early on, I don’t know exactly when, but it must have been pretty early on, because they got interested in making watch displays and they wanted access to liquid crystal technology, and they did start producing watch displays and bigger displays, so yes. At the same time the consortium involved STL at Harlow, and they were interested in various kinds of display. One of the things they wanted to do was to put liquid crystals on silicon, to actually have a silicon chip that had liquid crystal on, which would get over the problems of addressing, but it raised its own problems with how you do this. It was very early days for silicon and would naturally be quite a small display. They were hopeful that you could look at this through a magnifying glass and they had a
company in Leeds which was making numeric displays for instruments. In addition Rank
Electronics had a company, also in Leeds I think, making numerics for electronics. So we had at
least three companies who had started making them, not completely independently of us. Racal
was independent of us until they discovered that we were in the business and then they came to
see us. IT&T or STL, they certainly were linked with Harlow so they knew all about our work on
liquid crystals. Rank I think was independent. At the same time we had other people who were
interested, because we were setting up consortia. We had Pilkingtons which existed then as a
glass company and their interest was in windows that you could turn on and off. That was quite
imaginative, that they could see the possibilities, particularly in buildings, not so much in homes,
in buildings, in turning a window off. It never came to anything, but they worked with us.
Trying to think of anyone else, there probably were others too. It was a developing area and
people were getting interested because if you had a flat panel you could do a lot more with an
instrument. We also had an intriguing way. A black and white cathode ray tube is quite easy to
make, which means it’s cheap, and it gives you very high resolution, in the sense that the
resolution limit is almost infinite horizontally and it’s only a question vertically of how much you
can displace an electron beam. The standard colour tube was a shadow mask tube – that takes you
back many years – but the way in which you get the colour is you have different spots on the
screen of different phosphors which emit different colours and automatically the resolution that
the picture that you see is the resolution caused by the finite size of those dots and you can’t
make them that small because you have the problem of making the shadow mask. So
automatically a black and white cathode ray tube will give you a finer picture than the colour
tube. [1:45:25] Now, one of the things we invented – and I say we because I was one of the
inventors, the other one was a man called Ian Shanks who still is around – was a liquid crystal
shutter which essentially changed the colour that was emitted by the black and white phosphor.
Now, a white phosphor – black phosphor, that’s a silly thing to say, it’s a black and white tube –
but you’re getting white light coming out because you’ve got a range of chemicals in the
phosphor screen that covers the whole thing. So you can imagine that the screen is not actually
emitting white light, it’s emitting blue, green and red or blue, yellow and red, and they’re all
coming out together and the impression you get is white. But now imagine a colour filter that
you put in between and if you swung a red filter in front you’ll see red light coming out from this
black and white tube because you’re blocking the blues and the greens and yellows. If you put a
blue piece of cellophane in the way, then you see a blue thing. Similarly, you see a red one. And
you can make a screen of liquid crystal if you know what you’re doing, which actually transmits
either red or blue or green. So if you imagine putting that in front, you can switch electronically.
So you can make a tube that converts a black and white system to a colour system, and we did. And we started licensing it to Tektronix. It’s not terribly useful for picture forming because it’s too slow, it’s not as good as an ordinary colour tube, but it does give you a very fine instrument, it gives you a way of measuring waveforms with different colours, a very high resolution, you get a very nice picture. And Tektronix did want to license it. Unfortunately we were working through the National Research Development Corporation, which was not terribly skilled in licensing negotiations [sighs] and they tried to push Tektronix too far in licence fees, which was extremely embarrassing for me because during these negotiations I had got on very well with the Tektronix management and they were inviting me to come and lecture and we were getting on very well, and on the other hand they were not getting on very well with the people from NRDC. And they pointed out they could get round this patent, and they could if they wanted to, but NRDC were not thrilled and in the end it didn’t happen, which was a big shame. In fact the tube was marketed in the UK by the GEC display company, instrument display – Marconi Instruments in St Albans. They did market it and it was a very nice system. It worked very well and did give you very high resolution and good colour. And that was an application of liquid crystals that was quite different from your normal flat screen television. [1:49:20] And this was the kind of thing you could do with liquid crystals as electro-optic media. There were a fair number of boutique applications for it that got round the problem of picture forming. Television had to wait. But displays are a very large industry. So you can see that there were a number of companies, which comes down to the question you asked which, was there industrial interest, and the answer is yes. And this was not confined to the UK, though it was quite active in the UK. So we were kept quite busy answering questions and encouraging people to get involved and obviously giving them some help and occasionally making some prototypes. And the group was developing all kinds of ideas. Ian Shanks came up with a very nice idea for discos, which is a way of switching colour and indeed was the basis originally, but if you put pieces of cellophane – cellophane is birefringent – if you put pieces of cellophane behind a liquid crystal and you then operate the liquid crystal from a loud speaker, basically, you can get the colour pattern changing. You project light through it, so the light changes with the sound. He patented that too and people have made that, not in large numbers, but people have made that. There are other devices, many other devices which exploit liquid crystals as electronic… and still are, people are still inventing ways. I saw one, actually it’s been submitted for a research award, quite recently – well, last week – for a new idea for exploiting liquid crystals. You see, what you have in the liquid crystal is something that is optically interesting and electrically interesting. The molecules change, in an electric field, they turn, they can spin, you can do all kinds of things with them in an electric field. At the same
time, they have refractive indices that change depending on the way you’re looking at the molecules, so you see a different refractive index. So you can use your imagination on different ways of doing this. The other thing they have is very interesting secure applications because one of the problems with having a numeric keyboard, for example, is that if you put a pattern on the keyboard that you’re going to set up each time and it’s going to be a password that you’re going to repeat, after you’ve been operating it for many months, you can see where it’s been operated, that it’s, the life has gone down. So you can actually see that there is effectively optical wear in the material because it’s been passing current. You don’t get that with liquid crystals, there isn’t any current so it doesn’t wear. So there is no memory on the device of how you’ve done that. So that means you can make secure measurements. The other thing is that because it’s low voltage, it is very convenient to have a touch screen that exploits it, and one of the things we showed early on was that when you actually touch a liquid crystal screen the capacitance changes, so you get an immediately electronic way of showing where you have touched it, which again is very useful and is now being exploited. So it’s not just displays, that’s the point I’m making, that yes, we were waiting for a pixel switch so we could make pictures, but there were plenty of things that we could do and that people wanted to do once they had a stable material. And of course it wasn’t just us, it wasn’t just the UK, this was the world doing things.

_Shall we take a break?_

By all means.

[end of Track 21]
Right now, the thing I must emphasise to you, that I really was working on flat panel displays and though all seemed well for liquid crystals, in fact we weren’t sure that liquid crystals were going to be the way forward and we had other technologies that we were working on, both at Malvern and at the companies, almost as insurance policies. But we didn’t think of them that way, we just thought of them as ways in which you could make displays. And for instance, one of the alternatives to liquid crystals was called electrophoresis and Plesseys were working on contracts for us on electrophoresis, which is a very nice display for looking at and imagine that you’ve got in a liquid, that might be a white liquid, black particles which you can attract to the front surface or repel from the front surface, so areas of the display will change from black to white. And it gives you a very clear picture. And they worked on this for some time, we were working on it with them as well of course, but it was mostly them, and the problem we had was that the particles tended to fall to the bottom, gravitational settling. Now, you might think that if the particles are very small, the Brownian motion is enough to keep them up, but it isn’t, they do fall down. The other thing we found was that the particles tend to clump so that they won’t all move at the same speed, obviously if you’ve got a clump of ten particles it’s going to move slower than a clump of one particle. So you might get memory effects, but then you get a different kind of memory effect which was that the blasted particles don’t always come away from the surface that you’ve put them on when you apply fields, they get obstinate and they stay there, and you call it staining. Remember, this was in the 1970s when we were starting our display programme, and in the end we and Plessey decided that this wasn’t going to work. Now what we didn’t think of was micro-encapsulation, that came later and if you micro-encapsulate these particles, then you get over those three problems, they don’t happen. And indeed, other people have done that, they’ve made a thing called electronic paper, and you see in the Kindle. Now, you can say we missed out there. I suppose we did. Plessey will say they did, but Plessey’s no longer exist in that form, so there’s nobody there to moan. But it doesn’t always work. I mean you can do your research and it doesn’t necessarily lead where you think it should go. [03:40] Another thing that we did a little bit of work on, though in fact Philips did more, on electrochromics, and ICI did too. ICI showed they could make a very nice display which changed in colour chemically when you put an electric field on, quite a small field again, it’ll only be a few volts, maybe a few tens of volts. Worked quite well. They said they were going to market it, I said, ‘You’ll have a problem’. They said, ‘What problem will we have?’ I said, ‘Well, you’re just chemists so you wouldn’t understand the problem, but actually the material you use is very close to paraquat and most
people think of paraquat as being a very poisonous weed killer’. They said, ‘Well, it’s not quite the same’. I said, ‘It may not be quite the same, but it’s very near the same isn’t it?’ They never marketed it. Philips also had an electrochromic but they never marketed it either. Now those are all displays which are what you might call subtractive, in the sense that what they do is they modify, they modulate light that’s falling on it or coming through it. You can put a light behind it and see it but they don’t give out light. But there’s another form of display that actually gives out light and you see it in LEDs. [05:15] But one of the things that we had been working on for some years was a panel that had zinc sulphide particles on it. You could evaporate them but in general they were settling on it. And that gives out a bright yellow colour. It has some peculiarities, it works off a much higher voltage, it’s something like seventy or eighty volts, but it is a very pleasing appearance and if you know what you’re doing you can get different colours in different areas. You can’t change the colour but you can deposit different dopings in zinc sulphide that give you reds and greens, so you can have a red, green and yellow display. And we worked on that with AEI, which was in Rugby. Actually we originally started work not so much under contract when they were down in Harlow, and then the group was moved to Rugby and we had a contract going with them, and the leader of the group was a gentleman called Aron Vecht – V-E-C-H-T. A-R-O-N, V-E-C-H-T, who was a phosphor expert, still is actually, though he must be even older than I am now. And we placed a contract with AEI when they decided that they were going to move the group to Wembley and half of the group was very unhappy about moving from AEI to GEC. Now AEI had been bought by GEC. It had been bought as a very big electrical power company. In general a lot of these combinations of companies weren’t necessarily takeovers, they quite often were friendly bids and you had GEC assimilated EEV, which actually was done, I think, because AEI wanted to buy EEV, and EEV did not want to be bought by AEI and they came to GEC and said please buy us. So GEC said okay, we’ll buy you, so they bought EEV. And that also involved Marconi, so… But now GEC had bought AEI and that had been done really because the government was very concerned about electrical power, they weren’t happy with industry and the machines it was doing and it wanted a stronger company, so they bought AEI. And that meant they were moving all the people from Rugby. But half of this group did not want to join GEC. GEC did not necessarily have a favourable image in the way it treated its staff. I think that was slightly unfair but it had the impression that the company was more important than the people. And half of the group decided they would rather go to the University of Greenwich, it wasn’t quite the University of Greenwich then, but it was – no, Woolwich. No, I lie, it was Woolwich. Woolwich, it was then Woolwich Polytechnic but it was going to become the University of Woolwich. And I was faced with two contracts now
instead of one contract, because half of the technology was available in Woolwich and half in GEC, and they hated each other. And I was essentially running both contracts from Malvern. Okay? So I would try and handle this as a consortium and we mentioned consortia before. Consortia work when people want them to work. So I come to Wembley, that’s where we normally had our meetings since it was halfway between Woolwich, I mean it was easier – we did have some meetings in Woolwich, but the consortium meetings were generally at GEC. And I’d start the meeting and ask one or other to start by saying what progress was and Woolwich would say, well, of course we’ve done this and we’ve done this, and you’d be amazed if I could tell you exactly what we have done, but of course I can’t really give away all our secrets here. But you’d be amazed. And I’d think, I’ve had meetings with this… never mind. So then I’d turn to Wembley and Wembley would say, well, we’ve done this and we’ve done this, but really I’m not free to tell you of the major developments we have made in the last month which open up completely new vistas to us. Anyway, I’d see each of them afterwards in the way, I said, ‘What the hell are you talking about, what’s this new programme, you haven’t told me about it’. And they said, ‘Oh, we haven’t done anything. We weren’t going to tell them that, were we?’ And I saw the director of the Hirst Research Centre and he asked to see me, he said, ‘We’re not very happy with what is happening here’. I said, ‘Well, I’m not either, but what are you suggesting?’ He said, ‘Well, it’s very simple, that essentially you should instruct Woolwich that they’re to give us their technology, they should pass their technology over to us. They can’t exploit it themselves and they should pass it to us’. I said, ‘But it’s a totally different technology to the one you’re using. They’ve gone a different way’. He said, ‘I know’. I said, ‘So what would you do with it?’ He said, ‘Oh, we’d suppress it’. I said, ‘Over my dead body’. And they continued to go separate ways. I stopped the meetings, they were nonsense. And they did go in separate ways. Woolwich set up a company called Phosphor Products, which limped along for a bit. Now I’m just trying to think, I’m pretty certain, but they did actually get Smith’s interested in making a display for car, the dashboards, and the main problem with the panel was its life and they did work on it for a time and they got the life up to about 16,000 and Smith’s reckoned that was going to be all right. There was a problem, they had it in a Princess, in an Austin Princess, and I remember driving around in this and – Smith’s was at Cricklewood – and it was a beautiful display, it really was nice, but… Although there was a problem with sunlight falling on it, but it wasn’t a serious problem because most of the time when the sunlight was worse the head of the driver would be in the way, so a shadow would be cast, so that was okay. It wasn’t ideal in bright sunlight, but it was okay. The main reason it fell down was on the chips, because people were making chips by then and it needed really 80 volts to work. It was a DC display, it needed 80
volts. Now, you could buy chips that were high voltage. That wasn’t the problem, and you could make a circuit for doing it, but they were so conscious of price. I mean they really were agonising over pennies on the price and in the end it didn’t happen. [14:00] Meanwhile, I’ve already mentioned GEC was making a display and they were more concerned with reducing the price, and they got the price down to about, I think, it was eleven pounds for a panel that was essentially about a foot by four inches, that was going to be for this music centre and do this. And eleven pounds was just about right, but it was pushing the price to do it, but in the end it was Binatone was the company and they said they really wanted it ten pounds, not eleven pounds. I have a feeling that they just were, they either were pushing the price down or they wanted an out, and they decided against it, but it didn’t happen. But Phosphor Products went on making displays for quite some time, some quite nice flat panel displays. But always the problem was the power required, but it was a very attractive display to look at. [15:10] Well, all that was left behind me when I joined GEC and I’ve said I was going to form a Chief Scientist Unit and I had to recruit people for this, starting more or less from scratch and recruiting young graduates and engineers and I had, was given an office and a big laboratory and nobody seemed to be terribly worried about the budget. I also was given the Long Range Research Laboratory, see how progressive GEC was, this was in Wembley in the Hirst Research Centre, there was a group of about ten bright people called the Long Range Research Laboratory and their job was to do research that had no obvious application but which would yield results on probably a ten year timescale. And they did things like looking at how phonons travelled in thin films, some low temperature physics, all kinds of things they were doing, which I now – they had a laboratory manager, but he now reported to me instead of to Derek. But I was forming my own group and my main task was to make a flat panel display that used polycrystalline silicon. And we were going to work together in a consortium with Racal who were going to make a flat panel display using amorphous silicon. And my first months in Wembley were taken up with negotiating with Department of Industry and Racal on how we would each operate and do this, and it was all going pretty well and then suddenly out of the blue Racal changed their mind and said they’d decided they didn’t want to do this. Never really knew why. [17:30] But it would have required quite a big investment.

*Can we pause for one second?*

[pause]

*Why were the DOI involved?*
Oh, because it was that DTI supported industrial applications, they had various schemes for supporting industry in those days. They would give you a grant, which essentially was a fraction of your investment, and you obviously had to supplement it by your own money going in, but there were various schemes and indeed, when it came to later schemes they had committees running them and I would often be chairman looking after the things. I was also obviously involved in defence contracts with GEC, so I was still going to Malvern and seeing my colleagues and negotiating with them from the other side of the table, explaining what we were doing. We were doing a range of things, actually it developed and we weren’t just doing displays. I can’t remember all the things we were doing, but we certainly later got involved in high temperature superconductivity but that came a few years afterwards. And then before long Derek was moved up to being Deputy Managing Director and I was moved up to being Director of Research for the company, [19:15] which meant I now had to get the funding in for the Hirst Research Laboratory, which was not easy because GEC did not function from the centre. Essentially the divisions managed themselves and could in fact compete with each other. There is a story, it may be apocryphal, I don’t think it is though, of the Chief Defence Scientific Advisers saying that they’d put out a request for companies to quote for a particular military system and they’d had seven replies, six of which were from GEC companies. And Weinstock said, ‘Well, what’s your problem?’ He said, ‘Well, we’ve got six bids coming from the same company’. He said, ‘Well’ he said, ‘there’s a guarantee there’s six good bids there then isn’t it? You just choose which one you want’. And the companies could compete with each other, and this led to some really irritating scenes. I can remember one where one of the people actually complained bitterly to me that the Scottish company had won the bid and he knew for a fact that they had never actually done what they said they had done as proving feasibility. He said, ‘They can’t have done, they haven’t got the people who can do it’. I said, ‘Well, I don’t know what you do about it because I’m sure they will take on the people now who will do it’. But that was the way it functioned, they just competed with each other if necessary. The only thing they had to do was make a profit. There was no compulsion on them to support research and Weinstock said, ‘Well I do not recruit managing directors to manage the company for one year, I expect them to manage it for ten years and to support the research they’re going to need in the future. If not they’ll be found out and they will lose their jobs’. And I said, ‘Well, that’s all very well, but I’ve got to manage a research lab’. And we had different schemes. He would give some money centrally but he said basically Hirst Research Centre has to manage with money coming in from the units, and I had all kinds of schemes I developed for the way in which they could give money
from different bits coming in and it was all patchwork. It was always very difficult and he
announced one year, I think it was the seventh year I was there, he said, ‘This year we’re going to
use the same method of funding that we did last year’. And I said, ‘I’m not surprised’. And he
said, ‘What do you mean, you’re not surprised?’ I said, ‘Well, I’m not surprised’. He said, ‘Why
aren’t you surprised?’ I said, ‘Because you’ve tried six other methods and you can’t think of
another one that we haven’t used before, that’s why’. He said, ‘Oh, let’s get on to the next
thing’. That was why. I mean basically he tried different ways of avoiding having central
funding, which was the way he should have gone, he just should have said, we’ve got this number
of millions of pounds and do your best with that.

Why the aversion to central funding?

He didn’t think he knew best how to do the thing. He knew best how to really run the company
as a whole, but not to do the details of what research they should be supporting and things, he
said it was up to them to actually say what research they wanted and to pay for it. And they
would do it out of their budget. He said the only other way to do it is to have a central budget and
he was very much against having a central budget. The way he ran the company was very good if
he had good people as managing directors who could take a long term view, but most of them,
they were too weak. They would basically give in to him. There was, I mean I got on very well
with him actually because I used to argue with him, I didn’t mind, I had nothing to lose anyway.
And he appreciated an argument and I don’t know if I’ve told you this, on one occasion he, we
were on the staircase at Hirst and he turned to me – he was surrounded by his sycophants – and
he said, ‘Why is it I never win an argument with you Cyril?’ And I thought for a minute, I said, ‘I
think that’s because, Lord Weinstock, you possibly don’t marshal your facts to the best’. And
everyone sort of recoiled back and he looked at me and smiled, he said, ‘I think you’re right. I
think you’re right’. We got on very well. We didn’t always agree, [24:50] but you could work
out the way he thought. We had to do our research budget each year, the same, it was a fearsome
week, I forget when it was, when all the companies had to come to Stanhope Gate and present
their budgets, and he would go through their budgets with a toothcomb and he would do the
research budget as well. But it wasn’t difficult to actually work out how he operated and we
would have a rehearsal of our budget. You see, there was a manager for the research labs who
looked after the laboratory, basically, and I was supposed to look after the research and not just
the research there, but there were other research labs, there were four research labs: there was one
at Baddow and two that dealt with high power that in principle I was supposed to manage, in practice they looked after themselves pretty well. And we were… I’ve lost my thread.

*Adjust your mic, one second while you’re…*

Oh yes, we were… we’d look at our budget, you see, and the manager, Steve Cundy it was then, would say, ‘Now this is the budget, this is what we’ve spent’ and I looked and I said, ‘Why is the bill for copying higher this year than last?’ He said, ‘What the hell’s that got to do with it, we’re talking about the running the research lab’. I said, ‘Why is the bill for copying higher?’ And he said, ‘Well, we weren’t very happy with the contract we had earlier, though it was cheap in fact the service wasn’t very good and the machine that was provided didn’t do the job properly, so we decided that this was a waste of money, so we had to have a new contract and this is more expensive, but it’s far better and copying’s more efficient’. I said, ‘Oh, great’. I said, ‘But your electricity bill’s up too. Why is your electricity bill up?’ He said, ‘Because we’ve extended the lab, that’s why, and we’ve got this and that, and that’s why. It’s also the clean room now, we’ve brought on and that of course is very expensive in power, but it’s necessary because we’ve got to have a silicon clean room for the company’. I said, ‘Okay’. So, we then went up to see Weinstock and he would say, ‘Look, this is just really not something I want to spend a lot of time on, I haven’t had time to look at the budget, let’s open it now and see if we can get through it quickly’. So we said, ‘Fine’. So he opens the thing and he said, ‘Why is your copying bill higher?’ at which Steve Cundy glares at me and he gives the answer. And Weinstock says, ‘Yes, yes, all right. Yes’. And he goes on and says, ‘Your electricity’s gone up hasn’t it?’ Steve again looks at me, so he gives the answer. And Weinstock closes the book and says, ‘Hm’. I said, ‘That’s quite remarkable isn’t it, Lord Weinstock’. He said, ‘What’s remarkable Cyril?’ I said, ‘That you just can open the book, as you say for the first time, and immediately pick on two weak points’. I said, ‘That’s really remarkable’. And he looks at me and said, ‘Oh, you buggers know all the answers don’t you, this is a waste of my time’. He said, ‘Let’s watch the racing instead’ or ‘Let’s see what’s happening in Parliament this question time’, and he just would then put the television on. And when I asked him this, as to how he operated, he said, ‘Well’, he said, ‘I expect managing directors to know all the details. I can’t question them about the things that they know well because they’ll have all the answers, but I get a feeling for what they are doing by questioning them on the details and then I can see how they answer by how reliable they are and how much trust I can put in them’. And that’s the way he operated.
It seems a very personal way of running a company.

It was a very personal way of running a company, yes. But it was a very successful company, but indeed, as we will come to later on, he had a lot of criticism.

What sort of chap was he to meet?

Well, he was always very friendly to me. He always… later on in the end I wasn’t too happy with the way he introduced me to some people when we were at exhibitions and things. He said, ‘Oh this is Cyril Hilsum, he’s a distinguished scientist in the twilight of his career’. I thought, yes, mm, that’s not very friendly. But I suppose I was by then getting on for seventy. Basically, you see, I didn’t have to retire at sixty-five which was the retiring age of the company, I stayed on way after that. So I had quite a good career there and it was very interesting and there were some very nice people. Of course I started getting - I was doing research, there was no question I was doing research in the chief scientist unit, I mean personal research and some of it on displays doing new forms of displays and improving things and of course we had the way in which we were going to do polycrystalline silicon. Indeed I was getting people joining me, I had built up the team. We had probably fifteen to twenty people, but I also had visitors coming and people would want to join the group for the summer and I had a Greek professor coming from Thessaloniki who came and worked with us, partly because his wife was at Hammersmith Hospital. She was doing research on blood there, and he wanted to obviously be with her, so he came and spent the summer with us, and he came up with a much better way of putting down polycrystalline silicon. We’d had a problem with putting down polycrystalline silicon over large areas from a vapour phase and he showed how by a very unusual variation you actually got improved material and we were able to patent that, and it did work. And we were doing different forms of display. But one of the things I started doing was getting interested in essentially how companies managed and how you judged the health of companies and things like added value in a company, how did a company add value, what was the logic in the stock exchange? And one of the things that GEC was being criticised for at the time, constantly, was the amount of money they had in the bank. They said GEC keeps its money in the bank, it makes more money out of really lending money to building societies and homes than it does out of making products. And I wrote an article called ‘Cash Mountains and Molehills’ in which I showed quite clearly that the amount of money GEC had in the bank was exactly proportionate to its size compared with the other electronics companies, that if you plotted on a graph, Hitachi, Sony, GEC, Siemens, NEC,
all the big companies in electronics, that the amount of money they had in the bank was proportionate to their size. GEC was actually a much smaller company than the others. I’ve probably got the reprint if you’re interested. It was in *Physics and Technology*. And it did actually start people lessening that attack. In fact I still remember there was an article in *The Guardian* that was talking about the cash and then it had afterwards – hyphenated – but we understand it is not different in proportion to other electronics companies. The main problem that Weinstock had was not with the money in the bank which was supposed to be there for actually buying companies – he would never buy a company because he would never bid enough for it. He would always sort of look at it and think it wasn’t worth as much as they were asking and then somebody else would bid higher and they would obviously win. But he wouldn’t be worried, he would say well, I don’t think they were worth it. But I can remember there was one company, a defence company, which was making some very interesting transducers, towed arrays transducers, which would have been extremely useful for some of the GEC systems, and he bid for it but he didn’t bid enough and I think it was Plessey actually outbid him. And that would happen quite often but he was never terribly concerned. [35:05] But we, we managed pretty well and essentially we were coming up with all kinds of ideas. We were doing good work in the laboratory, we did some very good work on magnetism and the German branch of GEC which was making credit cards got into trouble with the magnetic stripe, which was no longer working, and they asked us for help and we sent our magnetism expert over and in no time at all, I think it was about a week, he showed that the grain size that they were putting down had changed and was wrong. Showed them how to put it right and the managing director sent me a nice letter, which obviously I showed to the chap, thanking me, and saying would I send them an invoice for his time. And I wrote to him and said well, instead of paying for his time wouldn’t you like to support his research, because there’s no way in GEC that this kind of research is supported. We had no central funds, or very little central funds. Obviously I did give him some, but I said if this is the kind of thing that is going to be useful to you in the future, and you might like to support him partly, annually. And he wrote back saying no, I’d rather pay for his time, thank you. And I couldn’t charge him an extortionate amount for his time. That wasn’t permissible, but it was ridiculous because if it hadn’t been for the smidgeon of central funds that we had, we wouldn’t have been able to keep the man going.

[37:00]

*What’s a chief scientist unit actually do? What’s it for? When in GEC?*
Well, you’re there essentially as the head of science if they want to use you, of course the different divisions have their own head of science though they wouldn’t be called chief scientists, necessarily, but certainly the bigger companies like Marconi would have a whole range of very good scientists working for them, but they wouldn’t be doing the longer range things that we were doing. So at Hirst Research Centre we would be doing a combination of longer range things which attracted interest which I could sell to the different divisions as things worth doing and fire-fighting, shorter term things which they would pay for that were problems they had that people could do it, but we had… it was easier actually in the telecoms lab. The telecoms company was much more far seeing and would be willing to do things. We also had, the Marconi people would naturally use the Marconi laboratory at Baddow, which had developed when they were an independent company. Similarly, EEV was a very good company then for doing research and they would be doing CCDs that were very advanced and they were selling them to America actually and to NASA for space, because they were far better. But they relied on people in Hirst Research Centre for some of the algorithms that they were exploiting in their CCDs, which were the kind of thing we didn’t broadcast, but essentially were ways of averaging and getting over faulty elements. If you make a CCD or any big silicon chip there’s sure to be some faults in it and these can spoil its performance unless you have some ways of getting over it and we had some very clever designers at the Hirst Research Centre who knew how to do this and could do it.

This is CCDs for digital imaging?

Yes. Often for space applications, but defence applications as well. So we had a whole range of things. We had a very big effort on high temperature superconductivity where we had a robot sort of making different combinations of elements there and that had a lot of support from the company because various divisions could see uses for a good superconductor that worked at liquid nitrogen temperature instead of liquid helium temperature. So that was the kind of thing which I could get support for. But there are a whole variety of things that we were doing, new materials. There was a lot of software research, telecoms research. We also had facilities for making silicon devices because at that time we didn’t really have an active company making silicon but we could do them in the lab and we also had a gallium arsenide facility. By now gallium arsenide was being used for a lot of defence applications. So we were making gallium arsenide as well. And then we had an infrared laboratory, and I said that I wasn’t allowed to work in there for a year, but I was allowed to work in it now, so that was all right. So I did this. And of course later on in fact we bought the Philips factory there, they got fed up with it so we actually
sort of bought that and we had GEC Southampton. And, well I don’t know quite where we go from here.

[41:45]

I was wondering actually if you could actually describe what GEC Hirst was actually like?

[pause] Well, it was an old building, it had been there since the 1920s. It was set up when East Lane was a lane. Clifford Paterson had been recruited by the GEC management from NPL to actually run the first industrial research laboratory and that was in the 1920s and it was old-fashioned. He used to pay the scientists personally each week with a brown paper envelope. They would come and see him and he’d give them their wages for the week. The history of GEC is quite interesting, it developed from that and the company grew and grew, largely with electrical power, but of course it took over many other companies and that didn’t stop until the end when it all fell through, but that was after Weinstock left. We took over Plessey and became an even bigger company and I got more involved in sort of national things that are getting – here I’m talking about technology transfer – ‘Is too much being spent on defence research?’, ‘Justifying technology transfer myths and realisms’. I haven’t dealt with my being elected to – in three successive years actually – Fellowship of University College and then Fellowship of the Royal Academy of Engineering and then Fellowship of the Royal Society.

When did that happen? Or when did that process start to happen?

That was in the 1970s, late 1970s I think. ’77, 8 and 9, I think. Around that time. And I was the first one at Malvern to be elected to the Royal Society. 1979, FRS. I’m pretty certain it was FREng ’78 and FUCL ’77. So this was before I went, but obviously now I was in the unusual position in the Royal Society of being an industrial scientist. The Royal Society is overwhelmingly academic. They don’t like to think that, but it is true that they are almost entirely academic. Most of the people are associated with academia. Of course I hadn’t been completely independent of academia. I, while at Malvern had had very close contacts with Durham University and with Lancaster University and I’d lectured at Lancaster on MSc courses for… on solid state devices and semiconductor devices. At Durham I was a visiting professor in applied physics and I did lecture to the undergraduates in the final year. I may say that the attendance was sparse. On occasion – I would come once a term and lecture – and once I think there were as few as three, might have been four. The year wasn’t all that much there, but there
probably were twenty, but they didn’t always come. And they were examined. I mean it was part of their examination, it could be their degree or their terminal examination that the question could be based on what I had told them. And when I saw the answers I realised that I wasn’t teaching them very well, that was the kind way of putting it. Alternatively they weren’t paying attention, but I tried to make the lectures simpler and simpler, so they could actually answer them, but I don’t know that I ever succeeded. I don’t know, I didn’t distinguish myself as a teacher. But I did get very good attendance at one lecture I gave each year, which was, How do I judge my potential new employer? And this essentially was twelve questions that they should put to people on their milk round or when they visited a company so as to assess what the company was like, and that was a very popular lecture. I don’t know whether it was popular with industry but it was very popular. The way in which that was done, I thought this was a good idea, because I thought that the milk round was a bit one-sided, in which they’d all be questioned, but none of them seemed to think that they ought to actually, that they could be in demand and there was no question why they shouldn’t assess the job that they were being offered. And these were quite simple questions like, what, when the person interviews them says are there any questions you’d like to ask, say yes, what have you published recently? Can you give me a list of the publications? What is your policy about publications and things? What equipment am I allowed to order? Now, this is a difficult one because normally they’re not allowed to order anything, you see, so you judge this, say what am I allowed to order, and they wouldn’t know quite how to order this. And there would be a variety of questions like that that you could do, that they could not object to, they all were very reasonable questions and I knew that some of them, you would get good answers to. And there was no scientist who would interview you who would ever object to what had he published and what research is he working on now, and things like that, that you could ask. Some of the questions about personal responsibility they might get a little bit edgy about because quite often they would really be wanting an extra pair of hands and would not actually be wanting somebody who could think ahead, but still. And indeed, when I put the questions to Malvern, when I had ten questions I found we were only getting five out of ten, so I had to invent two more questions so we got seven out of twelve, at least I could say that we were getting more than half marks. But you would find in general that most of industry would not come out terribly well. Anyway, I can only say that people did throng to the lecture.

As a non-industrial scientist, were you surprised to be elected as an FRS?
Yes, I was surprised. Well, I obviously had to be surprised because I was the first one from Malvern. But they did have some industrial scientists. In fact, Eric Eastwood, who was the Chief Scientist for EEV, he I think put me up. The point was you had to get nominated and you had to have people who would support you, and I did know a lot of people, I knew a fair number of FRSs, but I was still very surprised. In those days you didn’t know that you were being put up, now you do know and indeed you have to supply some of the information that’s necessary. I had been asked by Eric Eastwood for some information but he didn’t say what it was for, and I had a pretty good publication record then, so that was why. So, well, anyway, I got in. [51:30] Well, where had we got to? Here I was getting quite involved in, I started talking about technology transfer, I have a sneaking feeling that that occurred because the Royal Academy of Engineering was interested in the financing of exploitation and there was a general feeling – I think this is right – that we didn’t handle this terribly well in the UK compared with other countries and there was a thing called Euro-CASE – European… I forget what the ‘C’ stands for. European Association… Centres of Excellence, or something. No. Scientific… Anyway, it was engineering, the engineering associations in Europe like the Royal Academy of Engineering, which got together, and I was asked to do a study on essentially technology transfer. And I sort of studied this from the point of view of essentially the way in which technology passed from one body to another and really whether something was constrained and was done freely, or whether it was done under licence. And I wrote an article for New Scientist on ‘Technology Transfer: Myths and Realism’.

Do you think there was myth or reality in the idea that Britain was bad at exploiting technology transfer?

Oh, there was no question that Britain was bad. I mean everyone knew we were bad at it but nobody knew quite why and it was, I mean it was the same in GEC. I would point out that if you came up with an idea in GEC that you wanted to turn into a product, that the rules of GEC were that you had to show a positive cash flow in three years, whereas the same thing in Siemens, now I have mentioned earlier the European Solid State Device Research Conference and the interactions I’d had with Leo Tummers and Walter Heywang, well this had led to me actually visiting those companies, well particularly Siemens, I went quite often to Siemens and I knew the way in which they functioned. But I knew that their idea of taking a new idea, idea of taking a new concept or product through to production was something like six or seven years. I said, well this is ridiculous, if you have an idea you’re far better off to take it to Siemens than GEC. And
this was the main problem, that essentially you were expected to turn something round on a much shorter timescale, which was impossible. So when you came up with a business plan for a development from the research labs, you basically would tell a lie, I mean you’d come up with mythical plans for the development, say it worked in three years, you knew damn well it wasn’t going to work in three years but on the other hand, the years would go by and the original plan would get lost, so you could actually do it but there’d be a lot of grumbling on the way, whereas Siemens it was much easier. This didn’t mean that we couldn’t turn things round. We could turn them round and we did [56:00] and new things developed in the company and GEC was a profitable company as a result, it did a number of new things and some of those certainly came out from the Hirst Research Centre.

Are there any particular successes you’d highlight in your time there?

There was a thing they did actually for de Beers, on putting fingerprints on diamonds. Essentially doing an analysis of defects in diamonds so that you could actually know what a diamond was and there was no way you can get round that even when you cut the diamond up, I mean you still could see the defect pattern in the individual bits. And that was developed and was very successful, a successful contract. We did a number of things for telecoms in the design of exchanges. We did, clearly there’s a whole range of things we did for defence that were done through Marconi, which developed into military systems at Southampton later on. I mean some of this was fillers, but later on we did infrared photocells for missiles and things. There were a whole range of civil applications too through the civil companies. What Marconi did, Marconi was essentially a defence company but at least a quarter of their income came from civil applications.

When was Marconi bought up by GEC during this period?

Oh, that had been years and years earlier. That had been part of EEV I think. They never quite… one of the problems of taking over a company is that you’ve got bits of your company that are overlapping with them and GEC had a very large company, group of companies in Kent – GEC Avionics – and the relationships between GEC Avionics and Marconi at Stanmore were always a bit edgy, they would always feel a bit of competition between them. As I said, the GEC divisions did compete, but I don’t think it was ever terribly friendly between Marconi and Avionics. We in
the research lab worked pretty well with both and certainly we did a lot of work on displays together with Avionics, which was pretty successful.

[59:10]

*I’m still having problems picturing what GEC Wembley is actually like to work in. I can see it’s a 1920s building, but what’s inside?*

Inside, it was a number of laboratories about the size of this room, maybe a bit bigger than this. There were a few clean room assemblies. It was quite a big area. I would say maybe the laboratories were a bit bigger than this room, maybe fifty per cent bigger or twice as big as this room. And it was several hundred scientists were working there. They had pretty good equipment. I don’t know quite how to describe it. There’d be, I think there are something like four corridors. If you have the front of the building this was probably seventy yards, maybe 100 yards wide and a bit more than that going back. So it’d be quite a large area. There was a balcony that went around, though it was essentially on one floor. There was a materials lab where materials were made, they would be making crystal materials and there was a materials research centre there. I’ve said there was magnetism, that went on in one laboratory. Then there’d be laboratories where there were people doing theoretical work with computers and software and things. Telecoms had a mixture of things. The mercury cadmium telluride was one of the materials that was used for infrared photocells and they would have their own clean room and assembly. That, as far as I remember, was near the back of the lab, and then there were these two clean room assemblies near each other, one of which was for silicon and one for gallium arsenide. And then there was a research facility for depositing semiconductors where there were various specialised machines for molecular beam epitaxy, there would have been a couple of machines for that. Probably forgotten some laboratories as well. But does that give you an idea of what there was?

*Whereabouts in this are you working?*

At the front. When I first got there I said I was given an office, I was given a secretary, an office and a laboratory and I had a darkroom associated with the laboratory because we knew we were going to look at some of the displays in the dark. And I gradually recruited people in and there were some offices, I think I probably had to have this built, there were some offices for the staff and I gradually recruited people, graduates obviously, some PhDs, but not all of them. But a fair
number were PhDs when I think about it, and as I say, not quite half of them but nearly half of them were female.

Why the high proportion?

That was our idea, that we were going to have a lab which was fifty-fifty because we thought this was a good thing to do, to encourage women to do science. And it worked very well, I will say the actual atmosphere in the lab was very good, it was competitive but not over-competitive. And we also had a variety of expertise, they weren’t all physicists. There were some chemists, some physicists, some engineers.

Sort of described a very sort of flexible working atmosphere at Malvern, people free to discuss work with other groups, that sort of thing – how does GEC compare?

Not very different. Not very different. People would know each other and I don’t think there were as many seminars as you tend to get in other laboratories, so there was a closer association of the individual laboratories with well, the parent companies, it’s a bit difficult to describe since it wasn’t true of everything. But you see the telecoms lab would get a lot of its funding from GEC Telecoms and they would have projects, some of it would be fire-fighting, some of it would be research from GEC Telecoms. They’d also have some central funds, but they would know they were more closely associated with GEC Telecoms. Similarly, the silicon production would be associated with GEC Semiconductors. They’d be doing research on chips and again, that would be paid for, so they would naturally be drawn towards that. Gallium arsenide was being done largely for Marconi as was the infrared. But that didn’t stop these people from talking to other areas if they needed some advice, I mean there was no pressure on them to do this or not to do it, that would be up to them to do it. And then there were some bits of the lab which would be generally used by the smaller parts of GEC like Marconi Instruments, and there was one part of GEC down in Slough, and they would place contracts with us for particular areas of research or development.

Did you enjoy working there?
Oh yeah. It was – oh, but there were frustrations, I mean the finance always was frustrating and I remember talking to one managing director about giving us support for high temperature superconductivity and after we’d talked for a time he said, ‘Well how much money do you want?’ I said, ‘£50K. And he said, ‘Oh my God’ he said, ‘That’s less than I spend on painting the building’. He still didn’t give me the money! GEC was very conscious of its individual units of its bottom line, probably more than Weinstock intended, but he never quite grasped the actual fear that people had of him. There were some funny things. For instance, Lord Prior came as chairman, I think it was, obviously retired from active politics and very nice man, he came to Stanhope Gate and on his first day I suppose it was, somebody came in and said, ‘Oh, what newspapers do you want?’ So he sort of thought well, I’d better have, I must, in this new position I’d better be conscious of what’s being said about GEC in the different newspapers, so he ordered a number of newspapers. He was a bit surprised at the end of the month to get a bill for them. And the people at GEC, the directors at GEC, paid for their lunches. They had a nice lunch but they were billed for it. And if they had a guest, which they did occasionally, I knew that if I was invited for lunch at Stanhope Gate, which I was quite often by Derek there or someone else, and they would get a bill for my lunch. That was the way it functioned. And Weinstock would also pay, he would say well, this is company money, you can’t just waste it. He was very conscious of it.

[1:09:25]

*Does that have any more implications on research?*

Well, he had a view on research, but doesn’t mean to say you agree with it. I mean he was very supportive of research, but he thought that all of the company should be supportive of research and they should pay for it and it should come out of their profits, basically. And when he saw their bottom line he would assume that they were paying for the research that was necessary. Of course, since he nagged them bitterly about their profits or the absence of profits, he didn’t realise – well he must have realised – he did not appreciate that they would economise on research, because it was the easiest thing to actually economise. The other thing they would always do is they wouldn’t pay their bills at the end of the month, because they knew he saw their accounts on the last day of the month, so they wouldn’t pay us until the first week of the next month, they’d just be overdue. But of course, this meant that our budget looked ridiculous because they weren’t paying their bills on time. And these were things you just put up with, you just learnt that that
was the way the company functioned. And it didn’t make much difference, it didn’t stop us from
doing research by any means.

*What’s your job mostly made up of by this point? Is it balancing the budget or are you still actively doing research?*

Oh no, balancing the budget was mostly once a year. I mean trying to ensure that you had the
money for the planning for next year, because of course this would also be important with the
recruiting and things as to how many people you could take on. So you had their plans, you had
your plans and you worked them over, we, essentially, a company was formed called GEC
Research, so we were managed as a company, GEC Research, and we had our managing director
who was John Williams, who actually was also the managing director of the Baddow site, but he
essentially had a responsibility as managing director of GEC Research, and there’d be the other
people. John Loughhead, who I do get involved with now, he was responsible for one of the
northern labs, and I forget which one, they were really in the Midlands. They were doing power.
They seemed to have much closer relationship with the transport companies; Alstom and people
like that, they seemed to have a better understanding of how money was needed for research. But
I could always keep the long range research lab going, I mean there was funding for that and we
could recruit bright people to it if they came along and we had a fair number there and they’re
scattered around the country now. And did very well, did some very good research. [1:13:15]
He was always, he was curiously open to doing newer things actually. We had a young woman
called Rosemary Lee who came into long range research and Weinstock was very taken. She had
an MBE machine, I think it was, and I had very good relationships with David Fishlock who I’d
met really in the early days of the laser when he was working for *New Scientist*, and he came to
the lab and it was Christmas ’62 and we’d just made our first laser and he took pictures of me for
*New Scientist* and kept in touch with us afterwards and when I moved to GEC by then he had
moved to the *Financial Times* and was their technology editor. And he came to see us and took a
picture of Rosemary leaning on, I think it was an MBE machine, and this appeared in the
*Financial Times* and was quite big and there was an article about the research that was going on,
particularly the research that Rosemary was doing, which I think was actually phonons moving
along a tube. And Weinstock immediately realised that this was like an advertisement for GEC
which would have cost him thousands and he was getting it free. So he immediately said he
wanted to see Rosemary and talk to Rosemary and I should come along as well. So I went and
we saw him and he started talking to Rosemary about what she was doing and she not only said
what she was doing, but she said what she wanted to do. And Weinstock then said, ‘Well, you’ve
got to look after this young lady and I’ll give you some money’ - which shook me rigid - ‘for her
projects’. And shook everybody rigid actually. But I knew it had only come from him seeing the
advertisement in the *Financial Times* and Rosemary had good ideas for what she was doing and
one thing that was really quite interesting. It was something we wanted to do. Rosemary had a
very powerful sense of smell, almost an embarrassing sense of smell in that she could sense if
somebody hadn’t washed their feet recently or if they had very powerful aftershave. And what
she wanted to do was to have a project set up on olfaction, in which we would make an electronic
nose. And there were parts of GEC that were interested in this, some of them were rather morbid
in they thought you might be able to sense a dead body from the gases it was giving off, but there
were other things you could do and Rosemary had a pretty good idea of how she wanted to
develop this. She had a couple of scientists who were also interested in working with her on it
and came up with a research proposal that essentially was based on measuring the frequency
change that you get from a quartz crystal tuning fork. The way in which watches had been made
had changed as people had developed technology for chips and people could use this technology
not just on silicon but on other materials. And what the Swiss had been doing had been to micro-
machine tiny tuning forks from quartz, which we used as the crystal element in watches to keep
their time. And it didn’t have to be a tuning fork, it could be just a cantilever that was a quartz
crystal, but you could buy these very cheaply. And what Rosemary and her group had worked
out, that if you could actually coat the tuning fork or the oscillator with a polymer, which
absorbed certain vapours, then if you put it in an atmosphere that had a small quantity of the
vapour, some material would be attracted to the polymer and that would change the weight on the
arm of the tuning fork or on the cantilever enough to alter the frequency. Now, one of the things
you can measure extremely accurately is a frequency and if you have a tuning fork that is going a
megahertz, a million cycles a second, which you can have though usually they’re a bit less than
that, you can measure a change of less than one part in a million, it’s a very, very sensitive
measurement. And they worked out that you could do this with various vapours. You needed to
design polymers that you could put on the tuning fork and then it would do this. So, that was all
right and Weinstock I think gave her £25,000 or £30,000. This was enough to get going, he gave
her money for other things as well which we’ll come to, at least I’ll mention one of them that I
can remember. Oh, she was doing something to do with animals as well. We finished up with
having some sheep that had various things in their blood, working with King’s College. You’d be
astonished at what I get mixed up with. But this one. So Rosemary put an advertisement in the
paper, I don’t know which it was, [1:20:20] for a young recruit to work on this. And to my
surprise, I got a phone call from a company in Switzerland called Firmenich and they said we’ve seen your note in the paper that you are starting a study on olfaction to detect small quantities of chemicals. We would like to come and talk to you because we would like to fund some research on this. Well, of course, being in GEC I was naturally interested in money coming in. So they came and it turned out that this was a privately owned company in Geneva which was one of the largest producers of fragrances and flavours and essentially they provided a lot of the raw materials for all of the large perfume manufacturers – Chanel and other people. I didn’t realise they didn’t make their own. Well they make some of their own, but they relied on companies like Firmenich, and Firmenich I think was the fourth biggest in the world, fourth or third biggest in the world for supplying this, also flavours and things and things that go into soaps and all kinds of things. And they said, we really want to mechanise our production. We want to increase it, we want to mechanise it, but one of our problems is impurities and we want to be able to detect impurities, particularly in our perfumes on line. At the moment the only way we can do it is by using our human noses and we have a range of human noses who will smell our products and they can detect when there is something there that shouldn’t be there. And I said ‘Well that’s fine, so why do you want to change it?’ He said, ‘They only work in the mornings’. ‘Why do they only work in the mornings?’ ‘They claim that after they have lunch they can’t smell accurately for several hours afterwards because they’ve poisoned their system and we don’t want to do this’. Anyway, so we thought this was interesting, Rosemary and I went over there and saw them and they immediately gave her a test of detection and they gave me the test of detection. She of course came out absolutely on top, she got everything right, she could match two, she could tell when something was wrong. Me, I was hopeless, I mean I’ve got a normal sense of smell but fortunately it didn’t matter. And they said we’ll fund the whole project. Even though Rosemary had money coming in, they said well, we’ll fund it if you just concentrate on doing what we want. Well, of course we could put in some other things. One of the things we could do, for instance, is we had a petrol pump company and we thought we could detect different octanes of petrol and things like that. That we could put in. So, they… so we started a project to do this. We found the polymers to go with different things and we worked out how to do this, you can do this with an array of six or ten things. There’s a lot of technology comes into it but you can do it. And we recruited a young chap for doing it and it all worked very well and one historic day they detected an impurity with the prototype nose we had supplied that the human noses had not detected. And they were as pleased as punch. Anyway, this carried on for some time, but later on Rosemary was promoted to a job in Marconi in Stanmore, but the work continued. In fact I think it moved, this was more or less at the time I was leaving, but not quite, before that. And there
was the, they had the, I think it was the 125th anniversary of the formation of the company and they a day of celebration with talks and they asked me to give the final talk on this, sort of explaining this great victory they’d had in this. So I obviously got together with Rosemary and the young chap who’d done a lot of the work and gave this talk and there was a lot of opposition in this from the people in Manchester who also had a technique for doing it. But their technique was based on measuring a change in resistivity of a polymer and I pointed out that they had to calibrate theirs and ours was clearly more basic than theirs in that we were detecting a molecule being deposited, whereas they were relying on the molecule changing the conductivity, which was one stage further on, so ours was simpler. Anyway, I noticed that at the end when there was applause there were a number of people in the front row who were not clapping, so I checked afterwards with the man who was sponsoring us and I said, ‘Those people weren’t very appreciative’. He said, ‘I’m not surprised, they’re our human noses. They were the people you’re displacing’. So that was a very interesting sort of piece of work that was done and there’s no question that it could have gone further, but I’m not sure what happened in the end.

Unfortunately the sponsor at Firmenich developed cancer and died very quickly and it’s always quite difficult to get continuity. I don’t know quite what happened, but it was a nice development and it clearly was successful and one of the things we also showed was that you could electronically detect the fumes coming off from petrol of different octanes and see the difference between them, which was interesting. [1:27:17] The other thing that Rosemary was keen on was essentially cathodes doing field emission from sharp points, which has a number of applications for cold cathodes and things, and again that was supported and was quite successful, though a bit more difficult to do because it relies on keeping the constancy of work function over a sharp point and we managed to take that to a certain stage. But I bring that up to show you that Weinstock could be persuaded to support certain projects and he did that quite generously for several years.

[1:28:07]

I guess we should probably call it a day in a moment, but I had one closing question really, which was I was wondering if you could just sort of sum up for me how being an industrial scientist differed from being a scientific civil servant?

Well, there was obviously a difference in generality, in that as a civil servant I had moved to the stage where I was obviously interested in the exploitation of the research we were doing, but that exploitation could be done through any company, mostly in the UK though if there was a foreign
company, particularly an American company, it still would be possible. But you wouldn’t be linked with one company and indeed, you tried to bring together in consortia the powers of the whole country, including by now academia, that most of the consortia including obviously those I’d had nothing to do with. I mean Ted Paige started an acousto-electric consortium which also was extremely successful, but it was run in the same way and he had academics in it. Hull University was obviously part of the liquid crystal consortium. So you had a wider spectrum of who you were working with. There also, as far as I was concerned, no real budget restraint. There was a restraint on personnel, that you could [not] recruit new people without having a vacancy or without having approval for a vacancy.

*At which, sorry?*

At Malvern. You could have money but you couldn’t have people. Now there were ways round that, that I mentioned Colin Waters, he essentially was a Merck employee and we’d had a Merck person working with us for a number of years. It wasn’t the same person, they changed, sometimes we recruited them into our group, but they didn’t have to. And you could have guest workers as well. We had a number of guest workers from the States who came in in the summer and did very effective work, some quite distinguished people came and worked with us that way. But it was always… but there was a limit on the permanent civil servants that you could take on, though some of them weren’t permanent, they were taken on fellowships. There was a limit, but there wasn’t a limit on money. Now, at GEC it was the opposite way round, that you could recruit people as long as you got the money, nobody worried about that. And there were various ways in which you could get money, you could sort of weasel it out from the central funds or you could persuade one of the companies that it was worthwhile, and then you would recruit somebody and you were able to recruit some pretty bright people. I recruited one who was the top engineer of the year from Cambridge, and he was extremely good and came in and he later on went on to production, but finally we lost him. Though he actually came back at one stage and found he was working for the same company I was working for, Cambridge Display Technology, but that’s a coincidence. But that was the difference. And the other difference was, you couldn’t do research that was going to be exploited by another company that was a competitor. There was no objection to us doing research for Firmenich because GEC wasn’t into fragrance and flavours, so that was all right, and indeed they could see they could benefit from this in some of the other applications as we developed these skills. I think the project is still running actually, I think it’s running at Baddow now. They’ve obviously got some applications for it. But I couldn’t do
anything that was going to be exploited by Racal or STL. I might be able to work with them on a consortium, but that would have to be done quite carefully and would only be done if DTI was doing it or the EU. On the other hand, for high temperature superconductivity we could [1:33:20] bid and get a European Commission contract which involved us working with Pirelli in Italy and Alstom and ABB in Switzerland and Sweden. That was okay, that you could do. But you couldn’t really collaborate with UK companies. It wasn’t something you were conscious of every day, that you were looking for money and knew you had projects. You would quite often have problems put to you from one of the companies, saying we’ve got this problem, or this has arisen, can you help us? And then they would pay you. I mean it was quite standard, you had standard rates that they would pay you. You wouldn’t be making much of a profit, but you would be making some and you would be using your staff on it and you obviously had to plan how you sort of did this, compared with what you were doing as your research programme. And once a year, certainly, you would go in with all the companies and this did require quite a lot of planning, for the support that you’d be getting for your general research programme from the companies. But once that was done you then would be doing your research programme, you would not be worried, you would be doing both things. You also were doing things for DTI, I mean GEC was not a popular company with DTI because they knew that GEC was interested in maximising the income they would be getting from DTI, but they knew that GEC was a very powerful laboratory and a powerful company and they’d be getting results from it, so they would want to work with us, which meant that I would quite often be the industrial member on their committees and sometimes the chairman of committees. Similarly, I would be operating with the Defence Scientific Advisory Council on various studies that would be done and most of those would involve defence companies as well as some academic labs, but it was a good mixture.

_Shall we call it quits for the day?_

I’m quite happy to call it quits, yes.

_Thank you very much._

[end of Track 22]
Well, I was approached in 1987, I suppose it was, asking if I was willing to be President of the Institute of Physics. It was obviously a compliment, it wasn’t as much of a compliment as you might imagine because they did try and alternate – actually, it must have been well before that, it must have been two years before, for a reason which will become obvious – which is that they wanted to alternate in the presidency between people who worked for either government service or industry and academics, because the Institute of Physics set out to be an institution for all physicists, no matter where they were working. So they wanted to represent industrial and defence physicists, then defence physicists were more numerous so they were quite important, but industrial physicists were around as well. So in ’86 when they were going to have obviously an academic taking over, I was approached by somebody who said, well, would you be prepared to be President of the Institute. Well, I’d been associated with the Institute for some years, I’d been on Council and done things and I thought of it as my institution probably more than the IEE, which I was also linked with. And so I said, ‘Well what does it involve?’ And they said, ‘One meeting every three months and as many dinners as you can eat’. I didn’t think that was a good thing, but in fact it didn’t prove that way, the reason, I mean we didn’t have that many dinners because the Institute was not terribly well off and couldn’t even afford its own annual dinner, which put us in a slightly difficult position, I later discovered, because most institutions invited the President and his lady for dinner and we couldn’t really reciprocate. What we did is we invited them for a lunch at the Institute, which was in Belgrave Square, which was not that remarkable, but still. Anyway, I agreed to do it and it all seemed fine, there was plenty of activity, plenty of things to do, [02:23] but I discovered that we owned a research laboratory called Fulmer Research. Now this was intriguing because it had been gifted to the Institute by ICI who didn’t need it as a materials research laboratory and the Institute had taken it on. But when I started sort of working with them I was Chairman, basically of the board, as being President, I got a bit concerned as to whether we weren’t losing money. The people who were actually running the thing said no, no, we’re doing very well, we have lots of orders and we are doing good materials research and doing very well. And I said, ‘Well, I then can’t understand why our bank overdraft increases every year’. And they said, ‘It does?’ I said, ‘Yes, month by month it goes up by £10, 20K each month, until at the end of the year it’s another £100K more than it used to be. Why is that?’ I didn’t get a good answer. Well, I discussed it within the Institute and with the treasurer and he said well, we’ll put someone on the board with you who actually sort of understands all this and can help them, I mean a professional, so that was fine. So
his first meeting he came and there was a hiatus in the conversation and he said, ‘Of course, I think I should point out to you that we’re probably trading illegally’. And everyone sort of stopped talking and looked at him, said, ‘What do you mean, trading illegally?’ He said, ‘Because I think what is happening is essentially we are trading at a loss and there is no plan for actually reducing and eliminating this loss. So we’re trading illegally. And of course that means that the individual members of the board are responsible’. Well that did get their attention. I’ll cut a long story short, but essentially we agreed that we would sell Fulmer, and that wasn’t that easy to find somebody who would take it over, I mean partly because of course we had the problem of the staff and the pension funds and things. But we did find a very good estate agent, which doesn’t seem to go terribly well with a thing like the Institute of Physics, but we knew that we had a very valuable site in Fulmer village, which was prime land. And eventually, by working closely with the local council, he was able to sell the building to Pioneer, a Japanese company who were looking for a laboratory that they could set up, presumably as a research lab and factory. And in fact we made about three million pounds on it. When I say made, in fact we had to pay about a million pounds to the organisation which was going to take over Fulmer and move it to a site south of Oxford, basically, and take the staff that wanted to come and take the pensions. That was about a million pounds’ worth, roughly. Similarly, we discovered that a number of our customers were not very happy with the service they were getting from the management and again, I think that cost us the best part of a million pounds. But it did mean that the Institute was getting a million pounds as capital instead of losing £100K a year at least. So everyone was very happy. And in fact the Institute took off from there. [06:45] They’d also benefited because the previous President, who had realised that we were losing money on one aspect of the publishing company and had managed to sell that, I think also for about a million pounds, so the Institute had benefited considerably during two presidencies and it essentially never looked back, whereas I think it had about 10,000 members when I gave it up, it’s now got between 40 and 50,000, so everything went very well. So that is something that was very good. Of course I stayed with GEC, I was working there as Director of Research for some years until I was at a fairly indecent age to continue. But I still continued with them for some years after that indecent age as a consultant until I did finally give up. Now it’s interesting to know that this was at a time when I was not actually doing active research. I didn’t have time to do active research, I was running a group of about twenty young people that I’d been commissioned to set up as the Chief Scientist Unit. I had to pass that on to someone else when I became Director of Research but I still took a particular interest and I was doing things nationally. But I was getting, as I said, quite interested in actually the funding of industrial research, something which has become more
significant lately. And I wrote a series of papers. There was a lot of criticism of GEC, which I may have mentioned, on the fact that we had a lot of cash, but I did write a paper for *Physics and Technology* pointing out that the amount of money that we had was just proportionate to the size of the company, you could just compare us with companies like Siemens and Hitachi and Sony and could show the amount of money we had was just proportionate to our size, it wasn’t remarkable. I also got interested in added value, which is how does a company function. I was stimulated in this by a friend, Frank Jones, who I’d known for years and I mentioned earlier from his time at Malvern, and he later went to Philips and became Managing Director of Philips UK and he introduced me to the idea of working out added value for a company to see an analysis of what it was doing and was it being productive. And I looked at various companies, including of course GEC, and it was quite illuminating. This also got me involved with the Rank Prize Funds, because Frank was the chairman of the Optoelectronics Advisory Committee and of the Rank Prize Funds and a trustee. And when we come to awards and things you will see that in 1980, which was before I had joined GEC, I had been given a share of their prize, which was quite large, for scientists working in optoelectronics and my prize in 1980, my share was £10,000, which was enough to buy quite a nice car, which I did. But he brought me on to the committee. As a member I couldn’t, obviously committee members wouldn’t qualify for a prize because that would be a conflict of interest. But he brought me on and later when he died, which was almost exactly twenty-five years ago, which I suppose is ’87 is it? I became chairman of the committee and have been linked, and the trustee of the Rank Prize Funds and working for them since then, which is quite something and took up a fair amount of time, as we’ll see later. In fact I am giving it up next year, early next year.

*After how many years?*

After twenty-five years as chairman. The Rank Prize Funds is worth a special mention.

[11:45]

*What is it?*

It was set up by Lord Rank, whose name I’m sure is familiar to you, from Rank Films, Rank Hovis McDougall, Rank Flour Mills, Corn Mills, Rank Electronic Tubes and Rank Xerox. J Arthur Rank was a very religious man, he was a Methodist, and he had made a considerable fortune thirty years ago, it was over fifty million pounds so you can imagine today it would be
quite large, and he was going to leave it all for a medical charity, the Rank Foundation. But he
was persuaded by Frank Jones and others that he’d made this money as a result of scientific
progress in two areas of science; one nutrition and crop husbandry – Rank Hovis McDougall own
the corn mills – and also in optoelectronics, the films and Rank Xerox and Rank Electronic
Tubes. And he was persuaded that this was a good case so he left a million pounds for each of
those sciences, the development of each of those sciences and two committees were set up,
advisory committees, to do this and originally their job was just to give prizes, and they were
called the Rank Prize Funds, and as I’ve said, these prizes were quite considerable, they’re now
about £70,000 - £80,000, so they are in demand and they are very prestigious. We give them
every two years. [13:40] The other thing that I started, together with help from one of my
colleagues, Ian Shanks, was symposia in aspects of the science that are developing but aren’t yet
at the stage when people hold big conferences on them. And these have a specific formula. We
have about ten international authorities who come along and we have twenty young people.
Young is supposed to be under thirty, though sometimes they creep ahead and of course if women
have had a career break then you’re a bit flexible. But there are twenty PhD students or PDRAs
or people from industry who haven’t made a name for themselves. And these are all shut up
together in a hotel for two and a half days, two to three days, and everybody has to contribute.
The international people will give a talk for three-quarters of an hour, the young people have to
talk for fifteen minutes, on a topic that interests them, but usually is their own research. And they
benefit immensely from having the international experts viewing what they’re doing and talking
about it to them. They can’t get away from the hotel. Originally actually there was no transport
anyway, because I took them in my car and there was a coach and then the coach left. Anybody
that wanted to leave had to get not just my permission but my actual collaboration in taking a seat
in the car, which I will say was not used very often. Later on we migrated to the Lake District
where we do have a… we have four symposia a year in one of the two best hotels, either in
Grasmere or in Bowness, and everything is paid for including bar bills. I’ve only once had any
problem with people drinking too much and that wasn’t one of the students, that was one of the
international experts who had to be told that he wasn’t setting a good example – I will not
mention his name. And that’s still going and the nutrition people decided that this was a good
thing, so they also ran some. They don’t always have theirs in the Lake District but it’s always
the same pattern, more or less. And people look forward to it and they quote it, and particularly
the people who have helped in the organisation, put it on their CVs, they’ve organised Rank
symposia.
Why did you think it was important to actually hold them at all?

We could see the value of it. We started it without intending it as a series. We started them on a topic that was an interest of one of the members, on Langmuir-Blodgett films, and he thought it would be nice to have this meeting and we all agreed, and it was so popular with the people and they valued it so much, particularly, well both sides. The young people valued it from the contact they had closely with the experts, particularly at the bar in the evening when they could talk about their ambitions and what they were doing and would set up visits, but the international people also valued the relaxed atmosphere by which they could get close. They did get an opportunity of presenting their own work, but it wasn’t necessarily original, I mean it could be something they’d done. It was easy for them because we insisted there’d be no written record, they didn’t have to write something for publication, and everyone felt that the actual formula of it matched what they liked doing and so from that we decided to run another one and then another member of the committee wanted to run one, so before long we had a pattern developing. And it still exists and we’ve got a programme going for the next two years.

[18:15]

Who’s the ‘we’ here? Who else is on this committee?

The committee is almost entirely made up of Fellows of the Royal Society, or in one case a Fellow of the Royal Academy. Obviously they come and they go, they don’t come and go that fast. They like staying on because they enjoy what they’re doing, they usually depart because of ill health and getting too old. But there’s a whole variety. One from St Andrews, Ian Shanks is ex-Malvern and Unilever, there’s two - one was at Imperial College, now has retired, another one is still at Imperial College - one runs the Microsoft Research Laboratory, and two represent the eye. We don’t just think of the electronics side of optoelectronics such as television and lasers and light emitting diodes and things like that and fibre optics and communications, all of that, but also we think of the eye as an optoelectronic instrument, so two of the committee, one from Cambridge and one from Sussex, run symposia based on vision and colour vision and things like that. That I think is more or less who we have. We had one who was from Oxford and another one from Essex, but they’ve recently had to resign because of their health. So that’s who the committee are.

Well, what sort of things do you actually give awards to?
Well, that again is a question of great selection as to what we are going to award people for. We try and award them early before they’ve become really famous. We certainly gave one to Charles Kao before he got his Nobel Prize. We’ve given them for fibre optics, we’ve given them for work on lasers, we’ve given them for work on high power lasers, we’ve given a prize for adaptive optics which is now used in astronomy. Curiously enough, we gave that prize jointly to two people, one of whom had suggested adaptive optics in 1936 but it had never been adopted because nobody had the electronics to do it. Essentially, what it consists of is measuring the radiation that comes from a distant star and from an electronic imaging system, detecting the aberrations in the wave front, because from a distant star the wave front should be essentially plain, well spherical but with a centre of curvature so far away that it is plane. Now, if you measure the aberrations in that wave front in principle you can correct for them. So although the atmosphere is distorting what you are seeing, you can adapt to it, so you get adaptive optics. And that means that you now make a wave front which is exactly right so you can look at neighbouring stars and see them perfectly. And it is used in astronomy, but then it was discovered that for various aspects of Star Wars you also wanted to do it so there was defence funding going into it and unfortunately you couldn’t always get a star in the right region, but somebody invented the idea of sending up a rocket which would release some sodium in the upper atmosphere and you’d get an artificial star in the upper atmosphere which you could use. And we gave a prize to him and the man who’d thought of it in 1936. He was very surprised, very surprised to get a prize.

*What sort of criteria did you award things for?*

Imagination, achievement. We certainly hope to see that something has happened as a result. The committee individually will put forward proposals and they will be debated over a period of some months to select one or two. There can be two. They’re given every two years now, for the last probably fifteen years, maybe twenty years. They’ve been given every other year. There’s a slight discussion between us and the Nutrition Committee as to how frequently they should be. We wanted to give them every two years, they wanted to give them every year. In the end for a time we gave them every eighteen months as a compromise but then they had more of a shortage of money so we’ve now got a pattern, it’s every other year. There was one in February and David Willetts, the Minister, presented it. We’ve had various distinguished people; Margaret Thatcher gave it one year, so it is quite prestigious, the prize giving. [24:35] Now I mention it because
more recently we have broadened – and I’m going out of time now, but not to worry, I’m sure that people who listen will be able to compartmentalise – and it was decided largely because of Ian Shanks, who I’ve mentioned before, that we should also take an interest not just in current science going on in universities, but also in the provision of people who would do this science. In other words we should think about schools. At that time physics was getting into a pretty poor state and we decided we would have an initiative in schools to persuade children that science was part of their lives. We discussed this and we thought that the general way in which physics was presented to children was much more in terms that it was fascinating to the people practising it once they’d learnt how to practise it, but there was no common ground really with children. They would say that, oh kids are fascinated with the idea of black holes and particles and the universe as such, and we thought that that was questionable and we thought it was much more likely that children would be interested in the science behind the things that they use and see, like television. Now that had come about certainly with me, with being involved with a video company called SPE – Software Production Enterprises – which had done some videos for schools that really presented electronics to them as something that was real and I had helped with some of that, with actually doing one out of the ten programmes, but also with working with the presentation of them to the children who were fourteen or fifteen, and seeing how much the kids liked playing with things and how also they could be presented by young people to them. Well putting all this together we realised that in fact kids spend a lot of their time either watching television or on computers or on their mobile phones or on their CD players and if you actually put to them things like, did you realise that your CD player has two little lasers in it, they’d look at you as though you were mad. And when you said, well how do you think it works? And gradually we realised that there was an opening here and Ian Shanks agreed that he would start a pilot programme in Scotland on this – this goes back probably five years now – and he got some of the optoelectronics students at university together with some of the more progressive teachers to actually design kits that we were going to present to the schools and we finished up with three types of kit. One of them is solar cells in action, which they actually play with solar cells which are used to drive a little buggy and when they expose this to light they then can run the buggy and can compete with each other as to see who can run it farther, furthest. There’s another one called ‘Illumination and Communication’ in which they learn about fibre optics and they also can see the difference between tungsten filament lamps and LEDs. And it’s amazing the difference you realise when you have a hand generator and you try and drive each of these. It’s all very well to say that an LED is much more efficient, but you realise that if you try and drive it with a hand generator because you have to work very hard to light up a tungsten filament lamp, but it’s very
easy to get a bright LED going and this has an immediate impact. And the other one is colour vision and displays, in which they learn how you see colours and in addition then, how you see colour in a television set, because of course you don’t actually see a colour, what you see is a mixture of three colours that are done by the pixels, the picture elements in the display. And you have various experiments that the pupil can use himself – they’re interactive. The intriguing thing is that we had to train the teachers, because a lot of teachers of physics are science teachers and they’re actually biologists and their physics is a long time ago, so we have to run CPDs – Continuous Professional Development courses - for them and Ian in Scotland did this with essentially volunteer people who would help him. But we knew this was a pilot and originally it was financed by the Rank Prize Funds. They did get some money from the Scottish government, but we knew that we couldn’t leave it there if it was a success, so we decided we would extend it to England and then the committee decided that I would have to run it because it was too big for any of them to actually take on. So I was quite lucky in that I had some good friends who were involved with the Wolfson Foundation and they agreed they would match our investment from the Rank Prize Funds for three years. And then I also had a few other influential people in different trusts and things so we got some money there. So we started an English programme and the Association of Science Education agreed that they would administer it for us, so we worked together with them. The Institute of Physics provides ten trainers for the different parts of the country and at the moment we have probably 300 English schools that we’ve equipped and that adds up to, well, over a hundred Scottish schools. So we’re having an impact and now, almost certainly what is going to happen is the Association of Science Education is going to take it over and they will run it more professionally than we’ve been doing because they obviously are well into all the schools in the country, it’s a big job. And we hope to go into Wales next and who knows, Ireland possibly. So that’s taken up a fair amount of time, but it’s a worthwhile [32:07] initiative and we think we’re beginning to see signs that more children are getting interested in science because they can see that it’s part of their lives, it isn’t this sort of distant topic for brainy people, it’s the kind of thing that they should know, plays a part in their lives.

*Why do you think it’s actually important to actually make that effort?*

We need more kids into science and engineering, there’s no question of that. But more of them are interested, even some of the bright ones are interested in media studies and thinking they’ll go into television and things like that, we’ve always had a shortage, still have a shortage. There are more now coming into physics. Chemistry’s always been a bit better, but it’s still not right and
we’re still short of engineers, practical physicists. So yes, I think it is important and we lag behind other countries in this. The other thing if you look at it, and that links up since you’ve given me the opening, with the other thing I was interested in, was the balance of payments, essentially, the path to British prosperity. For thirty years we haven’t made enough, people talk now about a manufacturing deficit, but that’s been with us for thirty years. Even when we had big companies they weren’t doing enough research and so they were not doing enough manufacture that meant that people would buy their goods. And this got to a ridiculous statement – have I told you about the joint company that we ran with Hitachi? GEC made television sets and they worked closely with a Japanese company, I’m pretty certain it was Hitachi, and we had a factory in Wales, and that factory would obviously turn out one line of television sets, they may have been different sizes, but it would be one line, and towards the end they would get badged, either with the label Hitachi or with the label GEC, but they were the same sets and yet you could get twenty pounds more for a Hitachi set than a GEC set because it had some kind of imprimatur, some kind of feeling about it that you would do more. Now, you could understand that possibly if you were selling them in a shop, but in the staff shop people paid more – I don’t think it was twenty pounds, it was probably more like seven or eight pounds – more for the Hitachi one than for the GEC one. When they questioned the people they said, but you know it’s the same set, you’ve made it, so you know it’s the same set. They said oh yes, but the neighbours come in and see the set and they think more if it’s a Hitachi set than a GEC set, which is absolutely ridiculous. Anyway, that was happening, I mean it’s no great surprise, you know this, that essentially you look around, what have I got here, I mean that’s Panasonic or something or LG, and that one, I don’t know, that’s certainly LG. I mean they’re either Korean or Japanese, I don’t think I’ve got anything here… what have I got here? I’ve got Technics, that’s Japanese, all the way down. Don’t think they make them any more, it’s Japanese. And that’s what you have basically. And of course, now when you look at what’s happening to the large companies, we don’t have large electronics companies any more. GEC has gone, it’s now a defence company, essentially Marconi. We don’t have a research laboratory, the Hirst Research Lab vanished some years ago. ICI, our big chemical company, no longer exists as such, it was broken up and there was an excellent world class laboratory up in Lancashire, Cheshire or somewhere, that’s no longer there. Ferranti has vanished, Plessey has vanished. IT&T, STL, not there any more. The Philips laboratory doesn’t function as it used to, and that in any case is not British, it’s Dutch. And all of this, you could see the signs on the wall, so when I actually – the other thing that’s happened which has been quite significant, has been that the Ministry of Defence no longer sees that part of its mandate is keeping electronics healthy in the UK. The
way in which it used to function, and I had a large part in this of course, was that we would place research contracts through the organisation, CVD, that I mentioned, at the risky end of research so that that risk was taken out of the equation and it was understood that if the research was successful the company would then take on the development and make it and produce equipment which would probably going to be defence equipment, but of course some of it would have gone into the consumer world. Now, you can see that there were some logical breaks in that thought process into how it was done, though it still is done in the States, I mean there is large funding of defence research and I mentioned we have that ARP, the Advanced Research Projects Agency which again, changed its name back again to the Defence Advanced Research Projects Agency because it does defence research, but that has fallout and I could see that happening, and it doesn’t happen any more, so I wrote a thing for Physics Bulletin, ‘Is too much being spent on defence research?’ And then I did things, ‘Does industrial research pay?’ And I went into ‘Technology transfer: myths and realism’. But in Physics World I did publish a thing, ‘Regaining the Path to British Prosperity’ and this has come back again now. I showed the actual balance of payments and showed that essentially we had a £6 billion per month failure in manufacturing balance of payments, but we were rescued because we had oil and because we had the finance limb. But oil has vanished and I take it that our financial thing is under question now with what is happening. So we will be much worse off. And of course what happens is it does affect the value of the pound, essentially. I can still remember when you got four dollars to the pound. That’s a long time ago.

[39:50]

You raised two questions there in titles of paper and I was wondering if you could give me the answers to them. Were we spending too much on defence research in the eighties?

No, because it wasn’t just defence research. It was electronics research. If defence hadn’t put up the money industry would not have put up the money because always British industry has been too short term and you can argue about this till you’re blue in the face as to why it should be, but it is a fact that I worked with British, French and German companies and there’s no question that the European companies took a longer term view. And I suspected because of the way in which they were funded that essentially we always had pressure coming on us from the analysts as to what we were doing, why weren’t we spending our money, why weren’t we buying more companies, why weren’t we getting higher profits. There was no suggestion that you were putting in seed corn and laying down. And I do have a bee in my bonnet which I am pressing on
this at the moment, again doing this, that says essentially it’s the way in which we finance companies and they actually report their results that if you put up a new building it’s not in your profit and loss account, it’s in your balance sheet, it’s an investment, but if you spend money on research it’s expenditure, it is not an investment. Now that is nonsensical, because you get nothing out of research at the time that you do it. It’s essentially an asset. Now, this is actually serious because you can imagine that if you’re building up an asset, if you do a lot of research, then somebody looking from outside at what you are doing can say ah, this is not reflected in their balance sheet, it’s an expenditure which has reduced the value of the company rather than an asset which has increased the value of the company. So I bide my time and I would then make an offer for the company and I’m getting something cheaper. Well, this is not something that has gone down well. The reason for it is that many years ago you were able to do this and Rolls-Royce made a pig’s ear of it because their engineers over-valued their research. I’m not saying that you can do it without question, but what I am saying is it certainly is an asset, if it’s done sensibly it’s an asset, it is not just an expenditure. But if you look at any of our company reports you will see written at the bottom, research expenditure is treated as an expenditure in the year in which it’s incurred. There is no suggestion that it has value.

*Is that because of government legislation or company practice?*

It’s not clear as to whether it’s forced on people. It probably is practice which now has been approved, but I gather that the government is thinking about it. Because I was told, when I raised it as a question some months ago at a lecture, somebody from the government said, ‘Oh, we’re looking at this, someone suggested it’. And they looked at me and said, ‘It might have been you actually’. But I’m nagging. I am told that it doesn’t make any difference because they know how to handle it, so it doesn’t matter. But I think that from the point of view of presentation it just looks bad that essentially your research is a loss, it’s an expenditure, it isn’t something you should do. And there have been various discussions at the Royal Academy of Engineering where some of the analysts presented their views on company finance and what they do and they said, when I asked a question, they said, ‘Well, we’ve never actually said that a company shouldn’t spend money on research’. I said, ‘But can you point to any example where you have recommended buying a company because – buying a company’s shares – because it has increased its research budget?’ And they looked at me and said, ‘Can we go on to the next question?’ I mean it just doesn’t happen, because analysts in the City aren’t trained in research, they do not understand that you do spend money on research and it may take some years before you get a benefit from it.
You mentioned nagging, who do you nag and how?

Oh, anyone who comes or you’re sitting at a dinner with someone, you ask a question. I mean I was at a meeting of the Foundation of Science and Technology a few weeks ago and I put this forward and said, ‘Why isn’t it done’, and somebody from a company said, ‘Oh, we find ways round it by – and we do get grants for R&D’. Of course you get grants for R&D but your grants aren’t a hundred per cent and it still looks bad in the balance sheet and you don’t actually say we have done all this R&D and it’s now got value and is in our balance sheet. And the other thing is the practice of short term. When you’re going to do a new thing – have I said this before? I say it to so many people that I’m not sure what I’ve told you and what I’ve told other people [45:50] – you prepare a business plan and the business plan basically predicts what is going to happen and when the company is going to get a benefit from this new development that you’re suggesting. With GEC you had to show that the company was going to benefit in three to four years. Now that is very difficult. With Siemens the same thing is seven to eight years. So it’s fairly obvious if you’ve got an idea you’re better off to take it to Siemens than to give it to GEC. I wasn’t in that position. But that was, that’s sort of forced on people by – and they talk about it as short termism, well it is short termism and it comes from our finance houses and the need to actually get a return quickly. And that all comes from a lack of a method of predicting risk, that this is difficult in working out what are the chances of success, and most people will take a conservative view of that. They don’t like sticking their necks out and saying that we want to do this because it is going to work, and this of course is behind a lot of the problems we have at the moment with banks not being willing to lend money to people, and they do not assess the risk. As a result, they may make large profits at the moment, but they do plunge the country into debt and you do get this peculiar situation, as you can see, that our manufacturing balance of payments is ridiculously negative, but our finance balance of payments is ridiculously positive. In other words, we are only going for sure fire things, we do not actually go to risk and bank managers aren’t trained in doing this, they don’t have a technologist sitting by them. Now I am not saying that all ideas are going to yield profits, far from it. One of the things I started doing, probably ten years ago, was working with venture capital people and a small group of friends set up a venture capital company and they asked me to join them, and it was very interesting that essentially most of them, the majority, were skilled in finance but three of us were actual scientists, two in life sciences and me, and when ideas came to us we could question them in a way that they were not accustomed to. As a result we threw out most of the proposals coming to us on the grounds they
would not work. Now, it didn’t always work this way. This broadens, but the company, in fact we have four investments, one of which was short term and did make a profit, it made a profit of thirty per cent, but over a few years we’ve now got three companies - one of them is Peratech, that’s how I got involved with Peratech - that all look as though they are going to make money. It’s taken much longer than the investors hoped, but now it does look as though they’re going to get a reasonable return on their investments, even over the ten years that they have invested. But the other interesting thing is that we found that other venture capital houses [50:00] were copying us, because they could see that we were getting the technology advice that they were not getting. They were very good at finances; they could look at coffee bars and things like that and put money in, but when it came to something that involved technology they didn’t have the people working for them who could do it. Now I’m not talking about the really big venture capital houses which certainly did have, but you get some peculiar things happening. A good example is an Israeli company which a venture capital house asked me to look at, said would I look at what they were doing, and you may think this is very distant from the kind of things that I was skilled in, but this was a company that wanted to put a stent into the body, into the heart, for operations and they claimed that they could actually position a tool within a tenth of a millimetre. Now I thought that was quite a feat and I looked at it and said, well that’s interesting. The reason why it had been sent to me was they said it was based on defence technology. Well, I know a bit about defence technology, I did know something about Porton and places like that, but I’d never heard of anyone positioning anything to a tenth of a millimetre. So I asked if I could talk to the company and get involved with them, and it’s a bit unusual and they don’t usually like it, but they said okay, yeah. So I got in touch with them, I said, ‘Well, you say you’re actually positioning this thing to a tenth of a millimetre and you have a tool that is going in’. They said, ‘Yes’. I said, ‘Which bit of the tool are you positioning to a tenth of a millimetre?’ And they said, ‘What do you mean?’ I said, ‘Well, any tool has a certain size, so you have to say which bit of the tool is going to be a tenth of a millimetre’. And they said, ‘Oh, yes, mm. Would you accept a millimetre then?’ I said, ‘Well, it’s not a question would I accept, what the hell are you doing with a millimetre?’ They said, ‘Well…’ And I said, ‘And what is the defence equipment that this is based on?’ And they said, ‘Oh’ they said, ‘Mm. Well, that comes from a different field altogether’. I said, ‘Okay, try me’. And he said, ‘Well, we’ve been working on aircraft displays, head-up displays for aircraft and it’s the way in which you position your eye’. I said, ‘That’s rubbish, I worked on head-up displays for Marconi’. They said, ‘Oh’. I said, ‘A centimetre is good enough, you just put your eye in the right place, you move your head until it’s in the right place and as long as you’re within a centimetre you can see more or less what you need to see’.
They said, ‘Mm, yes, yes’. I said, ‘So, what is it?’ They said, ‘Well, it’s not actually based on defence technology’. I said, ‘But what is it based on, why?’ They said, ‘Well it sounds better in the prospectus if it’s based on defence technology’. I said, ‘Well, what is it?’ They said, ‘It’s a three axis magnetometer which we’ve miniaturised’. I said, ‘Oh’. I said, ‘How accurate is it then?’ ‘Oh’ they said, ‘it’s extremely accurate’. They described it. I said, ‘Why the hell didn’t you say so?’ I said, ‘That sounds really good’. They said, ‘Really?’ I said, ‘Yes, it sounds really good. I don’t know why you didn’t put this in’. They said, ‘No, that wouldn’t have gone down well at all with the people, no way they would have actually realised that you can miniaturise this to the stage that it’s there’. And I said, ‘But that’s not… I couldn’t get that from your patent’. They said, ‘No, it’s in other patents which we haven’t mentioned’. I said, ‘But wait a minute, you’re putting stents in and what you’re doing certainly is covered by a generic patent from another company’. They said, ‘Is it?’ I said, ‘Yes’. They said, ‘Which company?’ I said, ‘An Israeli company’. They said, ‘Oh’. They said, ‘We didn’t know about them’. I said, ‘Well, you’ll find them on the website, there’s at least fifty mentions of them on the website’. They said, ‘Oh, that’s interesting’. I said, ‘Yes, because forty-eight of them are legal battles they’re having with other companies that are going against their patents’. ‘Ahhh.’ So, you can see what you get involved in when you do things like that. And you don’t start out that way at all, but it does actually start coming in now and of course there is a much greater realisation of the value of IP, which I will say that I have learnt over many years, and it’s much easier now. I mean automatically now when I’m asked to look at any of the things that are coming out of academia for innovation awards or various other awards, almost the first thing I do is I look up the IP on the web, which certainly is a change when you see what has changed in the way in which research is done. Well, one thing that you don’t have to do is to go down to Chancery Lane. Did I mention this to you, the way you had to deal with very large volumes of patents that were covered in dust and dirt that you pulled down. Now of course it’s all digitised and it’s very easy, but lots of people don’t do it and it really is so easy to actually find out what previous work has been done.

[56:14]

*What was the venture capital company you got involved with?*

Westgate Hall, it’s called. That’s the one I belong to. There are a variety of other venture capital companies that I’ve done some work for in various ways and it gets you into some very interesting areas. I think it was two years ago that I was asked to look at a Chinese company that was developing a new form of lamp. It was pretty ingenious, I must say, I looked at it. You can’t
always believe everything that you read, that they send you, but it did sound quite imaginative. I haven’t heard anything of it lately, so it may not have worked, but it was certainly very promising.

[57:00]

To answer the other questions raised by one of your paper titles, does research pay?

Yes, yes. Research that’s done well does pay. It doesn’t pay immediately and you can’t always tell which way it’s going to go. I think I’ve given you the example of the door opener which we couldn’t have foreseen, but with Peratech, which we can get to now, if you looked at what Peratech was making, you could think of dozens of applications for it, in simple switches or in temperature controls or in aromatics, electronic noses and various things, and as far as a small company is concerned, or even a medium size company, this was the problem, that you needed to find one key application that it was vital for and had an advantage over other things that couldn’t be denied, that having a lot of things it could do meant you dissipated your resources on following things up and the thing we have discovered after eleven years that seems to be a very good application was actually not available to us at the beginning, because it’s touch screens for displays and if you tried to put forward a touch screen for a display ten years ago, even five years ago, you probably wouldn’t have acquired much resonance from the people who make the devices. The other thing you appreciate when you get involved in it is that the names on the outer casing are not necessarily the people that you have to contact. There are companies in China and Korea and to some extent in Japan that actually make most of these things and they supply them to the manufacturers who will specify what it is they want and then they get the components company to make them. So you have to discover who is actually making these things. There’s no point in going to the person who’s got the badge name. It might be a division of them but you’ve still got to penetrate into the company to find out who is responsible for making these things. And of course it does take some time to actually make a change in the production schedule of the company to introduce something that is new. But we are making some progress and now it is important that we try and find out what we are making. It’s not just a question of the specification, though I will say that the small companies are not actually skilled in writing a specification. When you work in the defence field you know immediately that if you’re making a product you have to say exactly what it will do and under what conditions will it do it; the temperature range, humidity, forces on it and things like that. Small companies will make something and they’re quite happy to make it and to sell it without really having a specification
and when I said to Peratech that they really ought to have a specification for what they were making, this was quite foreign. And they said, ‘Well nobody asks us, they ask for an example and a few samples so that they can measure them and see what they do, but they never ask us, sort of what is it intended to do, why should we help it?’ I said, ‘Because in two years’ time they will find that it’s not doing what they thought it was going to do and they will blame you for not telling them’. ‘Oh. Oh.’ So now we do write specifications and it’s amazing how many people will want to then work outside the specification, like working at a higher temperature than we actually said. And actually we can try it and sometimes we’ve been surprised, our specifications that we give out are very conservative and you can go outside it quite happily, though it’s better to be safe than sorry.

I guess we…

So that’s what I, one of the things I’m trying to do now, is try and work and we’ve got some quite good scientists, well very good scientists working with us, people at Durham University who know much more about it than I do. So it’s very encouraging to work with them and we do have a science panel that is surprising for a company with only twenty people working for it.

[1:02:40]

I think we should probably put a little sort of box around some of the things we’ve talked about. We’ve talked on quite a few different topics, but I was thinking about where we sort of picked up from last time, I was wondering how your career at GEC actually came to an end?

Well, I don’t know that it came to an end quite, it kind of… I was getting involved nationally in things and surprisingly enough, when I look at my career in fact, a lot of the recognition of what I’d done came after I’d stopped doing it. Interesting isn’t it? You see, if I look at the awards I’d got, I mean I did get, I said the Rank Prize in 1980 and before that the gallium arsenide community had given me a prize, the Welker Medal in ’78, and I had got sort of achievement awards from the IEEE and the IEE. But it wasn’t until ’87 that I got an award from the Institute of Physics jointly with the German Physical Society that was really a significant award, the Max Born Medal, which involved me going across to Germany and giving a lecture to a thousand people, that was ’87. Well, that was mostly for gallium arsenide and things like that that I’d sort of stopped doing, as you know, twenty years, well ten years earlier, well fifteen earlier. And then the next year I got the Faraday Medal from the IEE, which was at that time the biggest medal
they gave, again a bit odd. I got the CBE, which I’m sure came through GEC, in ’90. It wasn’t till ’95 that the display community gave me a medal.

Why do you think the lag?

I don’t know. I think it’s the way in which awards are given, depends on the awards committee that is functioning and I suppose they want to be certain that what you’re doing is working and it takes time for that.

Are there any of the awards that you’re particularly pleased to have got?

Oh well, the Royal Medal from the Royal Society five years ago, that was, that’s right at the top to get that. That’s one of their top medals and I got it for applied physics and that was very pleasing.

Why that one in particular?

Because it’s from the Royal Society and is one of their top medals and is a great mark of distinction, yes, that one. There’s only one given for applied physics every two years. But the other thing that pleased me was not my getting a medal, but a medal named after me, which is a bit odd because normally you would think that medals are only named after people after they’re dead. I don’t think people thought I was dead, but the Liquid Crystal Society has started well, five years, seven years ago, started a medal in my name for younger scientists, well, those in early stage of their career working on liquid crystals, which is very nice. That I thought was very pleasing.

Do you have to do anything involved with this?

No, I had to go once and present it to people. They haven’t asked me back. I don’t think I disgraced myself, but I do get a note from the people who’ve got it saying how much they look forward to getting the medal, so that’s nice. So yes, I have had a number of things happening since, but it does, it does take a long time.

[1:07:05]
I was just wondering if we could just put a box around the end of GEC. I know you mentioned that you sort of did consultancy work, but I wasn’t quite sure when you did retire from it. You did mention an indecent age, and I wasn’t quite sure how old and when.

I think I, the normal retirement age was sixty-five and that certainly passed. By the time I got to sixty-seven they were getting a bit nervous about me still being Director of Research, and I’m not sure at what stage I stopped being Director of Research, but I still turned up and still was paid until I was at least seventy, if not a bit older than that, but it would have been around the time I was seventy or seventy-one that I stopped working for GEC and started working for other people, which was interesting, because I then started work, I worked not as a consultant because I’d been advised by a Japanese scientist that I should never call myself a consultant, which is partly a term of abuse, but I should call myself an adviser. So I thought that was a good idea. So I call myself a research adviser and since I mostly advise companies I called myself a corporate research adviser. And in that guise I started essentially doing it seriously. I had been doing things intermittently, mostly literary things, reviewing and writing things while I was working, I had written the book on semiconductors and I wrote quite a few chapters for people, and I did some editing work for Elsevier – Dutch - some handbooks on semiconductors and encyclopaedias and things, where essentially I was editing and getting friends to write chapters for books that were quite prestigious and I was quite surprised to discover that some of these activities were multi-million pound activities, not necessarily my bit of it, but my bit of it would have been a fair fraction of it and certainly they would be selling 10,000 copies of a book that was costing over a hundred pounds, several hundred pounds. Well you only need to do some arithmetic on this and you can see that you’re getting up to large sums of money. Not that I was getting large sums of money and not that my authors were getting large sums of money, but the company was obviously doing quite well. So I did quite a bit of that, and that continued for some years. But then about the time I was leaving GEC, yes, maybe it was a gap of a few years, I started working for Unilever as an adviser, essentially on research looking at individual items of research that they were doing and talking to the younger people, but also talking to the more senior people about strategy and that’s when I got also involved in looking at Unilever as a company for its added value and things and that wasn’t too popular with some of the answers I was giving as to which way they should be going. [1:11:10] But I also had, also a very good time working for Cambridge Display Technology.

Who are they?
They were the people who took up the polymer display that had been developed at Cambridge University, it was a spin-out from Cambridge University to exploit work of Richard Friend and also Donal Bradley, Jeremy Burroughes, they had discovered that polymers could emit light. When I first looked at it they certainly didn’t emit much light and didn’t emit it for long, but when I became involved they’d had quite a lot of money put in and were doing it very professionally. But obviously I knew a bit about displays and they valued what I was doing. And I was surprised when I looked back to realise that I worked for them for about five years.

Doing what?

Oh, just going and looking at problems that had come up. I mean applying physics. There was one problem they had, they wanted to do inkjet printing and it wasn’t uniform and I looked at a lot of the literature on what happened when drops evaporate and I put in my two penn’orth on what was happening and how they could stop it, I doubt if they actually solved it in the way I had suggested, but I certainly gave them some advice. They were also very interested in how you got more light out and things. There is a problem that is not obvious to people who don’t have to work on these things in detail, that if you’re modulating light as you do with liquid crystal, you either have light falling on the front which is reflected back at you or you have a light behind it which you modulate by changing the transmission, and that all works fine and there’s no problem. But if you actually generate light within a material a large fraction of that light will actually be reflected back into the display. The actual yield that you get can be as low as ten or fifteen per cent if you have a high refractive index medium as you quite often do have. And the only way in which you can change that is by distorting the surface so that it’s no longer plane and parallel and have a lot of micro lenses, which is very expensive. But there are some other things that you might be able to do like gels on the surface and I worked with one of their brighter scientists on that. In fact we had a patent for some time on it, which was okay. I don’t know again that they needed to adopt it, but it was something that they had. But it is a problem with light emitting displays, that you have a number for the internal efficiency and the external efficiency and the internal efficiency says how clever you are at generating the light from the electricity. The external efficiency says how clever are you in the optics of getting that light out, which is not always easy.

[1:15:00]
Why did you just retire?

Well, as I’ve often said to people, I remember Lord Weinstock saying when he was asked that question, he said, ‘Retirement is not my idea of fun’. And I only do things that I’m interested in, I like doing them, I think I do a useful job. I judge whether I should retire from things by whether people are willing to pay me for what I do. You can easily be a nuisance and I’m sure that – a lot of academic scientists never retire and they will go back in and they hope they’re going to have a room where they can function, but I know that some of them are viewed as a positive nuisance when they come in because they will want to talk to people and chat. Well of course they do, their wives send them out because they don’t want them at home because they’ve never had them at home for long periods of time and they get under their feet, and they go in and they will talk to people and hope they’re being useful, but a lot of the time they’re not and you can hear people moaning. Well, I’m sure that there’s a measure of that in what I do when I go to places, but I’m not going to do it indefinitely for people and I judge really by how much I am wanted and I, one of the reasons why I am retiring from the Rank Prize Funds is I think I’ve done that for long enough and it’s about time other people came in and did it because I’m not doing a specific job that fits my talents. There are other people who can do it and almost certainly now they can do it better than I did because they’re more in touch with research. On the other hand, I do have a peculiar mixture of skills and experiences. That’s one of the things that being old does help you with, that you’ve lived a lot of things and most academics do specialise. If you’re a defence scientist and then if you’re an industrial scientist at a reasonable level, you have to cover a hell of a lot of topics. Now it can actually be very irritating to people when they ask for your advice on something and they will say, ‘Well I’m trying this’ and you say, ‘I don’t think that’ll work’. And they say, ‘Well how do you know?’ You say, ‘Well, we tried it’. And they say, ‘You tried it, it’s new isn’t it?’ I said, ‘No, no. No, we did it in ’64’. ‘I wasn’t born in ’64!’ ‘Well, that’s why you don’t know about it.’ And this happens, I mean there are an awful lot of things that you can refer to that either you know you did or that people in your group did it or people in your laboratory did it. So yes. Now you may not be up to date with a thing but you can know something about it, you can know some of the science. For instance, I mentioned CDT and inkjet printing, well GEC had an inkjet printing company that I obviously had to work with at times, so I did know a bit about inkjet printing. At the same time, I did actually help with an entrepreneurship competition at the Royal Academy some years ago and we actually had a proposal for an alternative to inkjet printing, an electro spray, which I learnt about through analysing the actual proposal. And I’ve worked with the 1851 Commission for many years on
their scholarship scheme, which is excellent and very high level, but it means I have covered, I
mean I look at twenty proposals a year. Well that adds up if you think about it, so I have got quite
a lot of experience in a number of topics and when you add that to the venture capital work it’s
quite unusual. And I have been involved with academia as well because I was a visiting professor
at Durham, I worked on courses at Lancaster, and I was and still am a visiting professor in UCL.
And at UCL for some years I worked with them, it was a paid job, to actually try and extract
useful products from the research done in the university, in UCL. And of course adding my
knowledge of IPR to that. So it is, I suppose, useful to people to have that combination and I
haven’t had much pressure on me to stop, so why should I retire. [1:20:59] I’m still working
actually, with the National Physical Laboratory, which again is very interesting to try and make
sure that the quality of their science is maintained. That is a government sponsored thing that the
National Physical Laboratory has been a pillar of strength in the community for many years, it
did some excellent research going back many years in fact. A lot of the computing originated
there, it’s not generally known, NPL fights against this, that Alan Turing worked there in 1947-8 I
think. I actually played chess with him, that’s how I know. I never sort of noticed he was
strange. I did win.

[laughs]

I still remember that, it’s one of my claims to fame, I beat Turing at chess. But they had a
fundamental reputation but the government decided some fifteen years ago that it didn’t want all
these research laboratories and I have touched on that earlier with the defence laboratories, but
they did it more generally with the laboratories that belonged to the Department of Industry,
which became the Department of Trade and Industry. And they wanted to put them under private
ownership and the Royal Society and the Royal Academy heard about this and they were furious
and there were heated discussions between the top civil servants in the department and the senior
people in the RS and the Royal Academy. And there was going to be a lot of opposition to this,
and in the end a compromise was worked out, which wasn’t entirely to the wishes of the Royal
Society and the Royal Academy but they weren’t in a position of strength. And it was agreed that
the government would go ahead with their scheme which was to form a GOCO. Now a GOCO is
a term that’s applied generally and is Government Owned Company Operated, and they put out
contract wishes to generally and people bid for them. And it was agreed that the Royal Society,
Royal Academy would actually nominate a panel of fellows who would be allowed to look and
comment on the science and ensure that the science was maintained at the high quality or even
improved and Sir Eric Ash chaired it originally and he asked me to come on to cover various aspects of the work, and I'd known NPL for many years actually, because curiously enough, as I say, the reason why I played chess with Alan Turing was that I was at the Admiralty Research Laboratory at Teddington which was just across the sports field from NPL and we actually were a division in their sports club, so I represented ARL and Turing I think was part of physics, though they may have been computer science or something then. So that’s how that happened. But, so I had an affinity with NPL and had known the people very well, so it was natural. In fact at one stage I was looking after their individual special merit promotions as the external adviser. So it wasn’t that foreign to me to be involved in that way and Ian Shanks who I’ve mentioned before also came on to that panel. And we functioned pretty well I thought for a few years until - the contract was first let to Serco and I think that was for five years, and then when renewal came up the thing was more formalised and written into the contract conditions was that there should be this panel and that whoever won the contract had to work with this panel. And that meant we got paid actually, which I don’t think we had at first. That was good, so we got paid. And that’s still running and indeed it’s now associated with NMO, the National Measurement Office, and our existence is well recognised and I do think it’s actually welcomed by the staff, they say that we’re the people who ask the best questions. So that still continues and, but Eric Ash gave up the chairmanship a few years ago and Ian Shanks became the chairman.

[1:26:30]

Are there any sort of particular changes that you have to sort of take part in and oversee in the process of it becoming at GOCO?

It’s not a question of overseeing, it’s much more advising NMO and advising… we go four times a year and we have a programme set out, so we will cover the whole programme of NPL and will comment on various aspects of it as we see it, so we get presentations made to us, we obviously ask questions, but then we will write a minute at the meeting and we can advise on what is happening, and for some years we were a bit concerned about the quality of what was going on, that it was actually getting worse under Serco management. But I can say that for the last year it’s been getting better and we’re much happier. This is of course not just a UK enterprise, the… most large countries have a metrological institution which ensures that industry standards are maintained in the products that are sold and there are three main NMIs, National Measurement Institutes. There’s NPL and there’s NIST, which is much bigger. And there’s PTB in Germany which is more academic but still operates at a very high standard and is very well equipped. And
NPL has to operate in competition with them, even though its resources, naturally being the UK, are not as generous as those. NIST is much bigger, NIST has 2,000 people and has a few Nobel Prizes as well for some of the things it’s done, so it operates at a very high standard. But we find that in some areas NPL is as good. It’s patchy, but is as good.

_How do you actually sort of make that judgement on the quality of the work it's doing? What sort of criteria?_

That’s a curious question. Through years of experience. I mean all of us have seen it. I mean the others, Ian still has academic contacts with Strathclyde, but he was Director of Physical Science at Unilever, he worked for me at Malvern for a number of years. Anne Dell is a professor of biochemistry and is an expert in mass spectroscopy at Imperial, Lynn Gladden is the vice-provost for research at Cambridge, she’s a chemical engineer. Peter Wells is a professor emeritus at Cardiff, he’s skilled in instrumentation of various kinds. We did until recently have Martin Taylor and John Enderby who are physicists at the top of their careers. So you do it normally as part of your job, I mean you’re looking at these kind of things all the time. The criteria are high quality research. [1:30:10] Also in the way in which it’s described. NPL is interesting because it functions, it has to function as a bridge between industry and academia in that it has to be in touch with what is going on, but it also has to present results to industry in terms that can be understood so that the industry standards are kept up. I mean industry has to produce goods and it has to have a specification, so it has to have some method of measurement and sometimes it has to be pretty accurate, sometimes it’s more of a question of indicating that something is safe, for instance with mobile phones, is it safe to hold a phone to your ear? Well, NPL would be looking at what happens when you do hold a phone to your ear. They will be consulting the medical authorities but they’ll also be looking at different designs of phone to see what is happening to the microwave-radiation within the body. And it will be measuring radiation. For instance, if you’re unfortunate enough to need some radiation therapy you hope that when you go into the hospital and they expose you to this instrument which you can see there, that they know what is coming out from it. Well, the reason why they do know is because at some stage NPL has measured it and that has to be done quite accurately because in standard radiation therapy there isn’t much difference between what’s going to kill cancer cells and what’s going to kill normal cells. So unless you’ve got the energy measured pretty accurately and the intensity measured pretty accurately you’re either going to do no good at all or you’re going to do damage if you’re not in this bit in between where the cancer cells are killed but the others aren’t killed as much. I
mean there always will be some damage, but hopefully it’s not bad. But that depends entirely on
where you are, so NPL is very important in things like that. But it also will be important in the
efficiency of products in acoustic baths for cleaning things, what is the frequency, what is the
intensity, things like that. The whole range of metrology, which they cannot completely cover of
course, they have 400 staff, but they will try and concentrate on the things which industry will be
finding important in a few years’ time. There’s no point in doing it in the past because that’s too
late, so you have to work out what is industry going to want. Industry will tell you what they are
wanting, that’s relatively easy, but they’ll also be telling you a bit, I mean where they are going
and you work out what they’re going to be wanting.

[1:33:39]
*I guess we talked quite a bit last time about the decline of government science labs and I suppose
the NPL's one of the last surviving ones really isn't it, on any scale?*

It’s got to survive because it’s legislated. I mean there are laws that say there has to be, the
government has to ensure that there are measurement standards which are set up, which goes
back many, many years. I mean you had kite marks and things like that. And there is a National
Measurement Office and that is linked with Weights and Measures, NPL just takes this a bit
further and goes into the science more.

*Do you think there’s still a place for a government lab…*

Oh yes.

*…in, you know, a world where there aren’t really so many and more work gets done in academic
and industry than it used to.*

It isn’t actually done in industry. I mean yes, they will measure things but you do have to have an
independent measurement, otherwise if you haven’t got an independent measurement you’re, I
mean in the hands of the people making the instruments or doing the measurements and you need
to have someone as an auditor of that. And it is a fact that, I mean every developed country is
doing these things, in fact NPL’s position in the league is now under pressure from China, Japan,
Korea and curiously Australia, which have seen the need for this and these are government labs in
each of these countries. Obviously you’ve got Germany and America, as I mentioned, there’s
also, I should have said, one in France, but there’s one in most developed countries, because each country sees the need for providing this help to industry.

*Shall we take a short break?*

By all means, yes.

[end of Track 23]
I was wondering if we could talk about Peratech for a little while? What does it actually do?

Well, Peratech was set up by an air force officer, quite some seniority, who was retiring – they retire when they’re fairly young – he was a bit older than most I think when he retired and he had an inventive bent and he was asked as he was in the process of retiring if he would look at conducting adhesives because they weren’t very happy with the conducting adhesives that were being used at the time. In doing that he, I suppose, stumbled across this material which is an insulator, it’s a polymer that’s filled with metals - in its original form, it now has semiconductors put in as well – that when you apply the slightest pressure to it, it becomes a very good conductor. And he thought this had applications so he set up his own company to exploit it and did some work together – this is in Darlington, which is quite near obviously Newcastle and Durham, and he got together with some of the science staff in Durham, also for guidance, and they started making this material in, well, an industrial park as it was then, in a couple of small units. And they applied for some venture capital help. They opened it up and I got involved quite early on, met David Lussey, the man who started it, and was impressed with what he was doing and we decided to invest some money in it, our venture capital group. Same time other investors joined us and it was decided with David’s agreement that I should come on to the board as a science adviser and the investment director – investor director. And I’ve been involved since then with all the ups and downs of a company over eleven years, more or less. For nine years at least we lost money and I’ve been involved with the IPR and various developments and trying to give some scientific guidance, some of which is useful, some of which definitely has not been useful, but you can’t win ‘em all. And now we, the last ten years – last two years – we have made a profit and we look like we’re going to make a profit this year and hopefully before too long, which is probably another two or three years, we will have a company of some value, so all of the hard work will have been worthwhile. They’ve got some very good people work for them. It’s still partly a family firm in that the secretary and legal adviser is David Lussey’s daughter and the CEO now is his son, who’s very good technically and also appears to be quite good at marketing.

[04:00]

What sort of things can you use the material it produces for?
You can use it as a speed control in electronic goods. At one stage it couldn’t take mains voltage but now it probably can with modern, with new developments. So you can imagine that you can put it in the handle of a drill so that when you squeeze the handle you control the speed of the drill. The harder you pull, the faster it goes. That can be extended to kitchen equipment for controlling the speed of mixers and things, and to children’s toys. That again you can control how high a dog jumps. You can, and we do, apply it to whiteboards, where as you press on it with a pen you can get writing to appear or you can get colours to change, or all kinds of things, depending on the thing. You can use it as a temperature control for central heating systems, you can also use it, and we have used it, in gas masks for Ministry of Defence, in seeing when the vapour coming out is insufficient from the amount from the chemicals that are there in the filters. Or you can use it to sense whether the gas mask is fitting properly around the face. You can use it to sense different volatile species because they will interact with the polymer. Erm… let me think what else you can use it for. You can use it as a force sensor for measuring how hard you are pressing on something.

*How different is it to other technologies that are used for this purpose already?*

Much simpler. Much simpler, you can do the same thing with circuits, but of course this is a tiny piece of material, it’s a button, or is a film, you can print it on to a surface. So it’s very small. You can put it in an object as thin as a credit card, so you can have a lot of functions that – and within that kind of volume and as I said, we use it for a display touch screen. Most touch screens will work by having four points of support and when you touch it, depending on where you touch it so you get different forces at the four corners, and we can sense where you are, but now we can actually put it on the display so that it can sense where you’re touching it immediately.

*What sort of work do you personally do towards this at Peratech?*

Ideas for how you put it down, ideas for how you measure it, checks on the controls as to how reproducible is it, ideas on the materials that you’re going to use and essentially ensuring that we maintain scientific control of what we are doing, particularly for stability, what happens to the material as it ages.

*Where do you actually work?*
Oh, mostly I go up there and give advice. We have meetings of the scientific panel, which I chair and we have minutes. But occasionally I actually do experiments. I’ve been doing some experiments on AC operation, we were looking at AC operation, so I did some experiments on AC operation. We also were interested in microwave transmission so I did some work on that, which wasn’t actually terribly productive. But I’ve got various samples here that I can use and test and do some work on. And at the moment I’m trying to work out how the transmission varies with pressure, because I think that would give me a handle on how the thing is working. It’s very difficult in these complex systems, because this is a mixture of spherical and acicular particles that are metallic or semiconductor in a polymer, and there are various theories on how it works, but the theories are not very developed, they’re more hand waving.

[10:25]
Did you work much at home on experiments before?

No. No, I set up the lab here when I started working for Peratech. Some of the things you can do now, you can buy equipment on eBay very cheaply, compared with what it would cost, because when laboratories fold or they decide they want more modern things, they then get people to come in and give them a ridiculous price for the old products and then they can sell them at a – well, they effectively auction them. And if you set your sights right and don’t try and be too greedy you can pick up recorders and oscilloscopes – the oscilloscope cost me sixty pounds I think and is worth probably an order of magnitude more than that. It was somebody who did test work for somebody and he was getting married and he reckoned he had to make some contribution to the expenses of the house so he was selling off some of his electrical equipment. But more often you’re buying it from a company that has bought things. It’s quite reasonable.

Are there any advantages from experimenting from home?

Well, the advantages are you can do it in your spare time, you don’t have to go anywhere. The disadvantages are that you don’t have the equipment that you would have in a normal laboratory. I mean you can do simple things but you can’t do sophisticated things. But it does test your imagination. Like, for instance when I was trying to re-set up this intruder alarm, I got the bits going but I want to make sure I’ve got some microwaves coming out and I thought I should have a microwave detector. But I don’t have a microwave detector do I, but if I buy one of these radar
detectors, in principle I will have a microwave detector, if it ever comes. I mean I think it’s all of five pounds. Yes, that’s the kind of price that you’re talking.

*What’s the problem?*

Well, it hasn’t come. I mean and you know what the problem was because I told you that they originally sent me a camera.

*Ah, but you haven’t told me on tape what the problem is. You told me over lunch what the problem was.*

The problem is that I’m not sure I’m generating microwaves yet. I know I’ve got a non-linear – hang on. Right. Now what is the problem? I’m plotting here current against voltage.

*On this graph.*

On this graph. And if you have a normal piece of semiconductor or material, that’s a uniform piece of material that isn’t a diode or with junctions in it, you expect to see a straight line at an angle, and the tangent of the angle is the resistance. Now you will see that as this, this goes up to about, I suppose that’s about four volts, and then you can see that instead of it going up as a straight line, it comes over and is more or less horizontal but is going up and down a bit. Now if you look at that on an oscilloscope you can see that that becomes very noisy, but on a recorder it doesn’t follow it. And that’s the region of negative resistance which I mentioned at a much earlier thing which I predicted and which happens. Now, in practice I should be getting microwaves out from that if it’s functioning in the cavity properly. But I don’t know if it is and I want to actually measure whether I’m getting microwaves out. Now for that you need a specialised piece of equipment which can function at very high frequencies, it’s not the normal frequency which you use, you need a radar detector. And I haven’t got a radar detector. Now, can I buy a radar detector? Well, I could buy a radar detector which would cost several thousand pounds, but I’m not interested in doing that, nor would Peratech be interested in doing it for me, so who would buy it for me? The British Library isn’t going to do it. But then on eBay, if I look up on eBay, I can see that there are radar detectors that are sold. They’re used for detecting radar, speed meters, so why shouldn’t I use one of those? And the answer is, there’s no reason why I shouldn’t use one of those, if only I can get one. So I ordered one and you know what happened
and instead of it arriving, a camera arrived. This was a ridiculous thing, it went wrong in their stores over somewhere in China or Hong Kong and when I complained they said, oh they’ll send me the thing, but it’ll take, they said, fifteen days to two months to arrive. I don’t know why it should take fifteen days to two months, I don’t even know if they’ve got one, but they have taken my money, so presumably they intend to send me one at some stage. But they sent me the camera quickly enough. Maybe they thought I wouldn’t notice the difference.

[16:50]

_I guess the one big thing we haven’t talked about over the sort of latter part of your career is what was life like outside of work? Talked about moving to London._

Oh…

But otherwise?

Well, I go on the net quite a bit. I don’t know quite. I’m mostly interested in work and science and engineering and I read things about that, I’m obviously a bit interested in scientific politics as applied to business. I find there are a number of things at the Royal Society and the Royal Academy that interest me. Two years ago I got involved in organising an event to essentially celebrate the 50th anniversary of the first working laser, which was a great success, we got a hundred people there and brought people over, brought over two Nobel Prize winners involved: Charles Kao who invented fibre optic communications which uses lasers, but also he was here to celebrate his Nobel Prize, and Charles Townes, the Nobel Prize winner who did the theory for the laser came over, he’s in great shape actually, though he’s in his nineties. So I organised that. I’m now helping with this year the fiftieth anniversary of the injection laser where I’ll be talking about our own work on that and the scene in the UK, there are people coming from abroad. They’ll be talking about what happened in their countries. So that kind of thing happens. I find that there are very few weeks that go by without me being asked to advise on something, to look at something, some proposal that is happening. The Schools Initiative has taken up a lot of my time. When that finishes I suppose I’ll find something else that will take up my time. I would like to do more experimental work for Peratech on things. I start things and then other things happen like people from the British Library coming and wanting to talk to me and then I realise I have to look up things and see what did happen in the past. I don’t find any problem in keeping busy.
What was life like, I guess in the eighties and nineties outside work? Talked a bit about the sorts of things you were doing, I’m wondering what the…

Well, I’ve always done a lot of work, when you say outside work. Well in the… I would say I’ve done more, less outside things than most people would think reasonable. I do occasionally go to the cinema or to the theatre but not very often. I used to visit friends more often than I do now. I do see my daughter when she’s in this country. I have a partner and we get together and go and see things occasionally, but she works pretty hard as well, and in fact she probably works harder than I do inside work. So… I used to play tennis for a bit, but gave that up about five years ago when I twisted my knee and was told that I really, you shouldn’t carry on doing this kind of thing or I wouldn’t be walking. I don’t know what kind of things people do do. I don’t do gardening…

No?

…which my, which Anne does, Anne does my gardening. I do have a gardener who comes and mows the lawn and no doubt he’ll be here before long, I think he’s been here on occasion when you’ve been here, and he will be mowing and no doubt will be making a noise into your microphone.

[22:00]

What’s family life like in the 1980s? I guess we’ve talked about your children when they were younger, but less so afterwards?

Well, of course your children leave home and do things. They either get married or they start partnerships. My elder daughter died fifteen years ago. My wife died now twenty-five years ago. My elder daughter died fifteen years ago, suddenly, and that was a great shock and I set up a trust in her memory through the Women’s Engineering Society which is quite good and it’s reasonably funded, it gives a prize every year to the most promising chartered woman engineer of the year. My younger daughter is an international figure for Channel 4 News and travels everywhere where it’s dangerous and she’s in Beirut at the moment.

What did your older daughter do?
My older daughter? She died, I told you.

*I was wondering what, before that?*

Oh, she was a scientist. She worked for British Aerospace for a time. She helped to design satellites and then she started working for UCL and helping in translation of science into industry and was just, she’d just got a permanent job established when she died. She left one son, my grandson who I see now and again. I saw him yesterday actually.

*Sounds a field fairly close to your own in some respects.*

Oh, what Karen did was very close to my own, in fact I was on the committee. I mean she was essentially running the committee and well, she was sort of administering it and I was on the committee, yeah, so it was very close to what I was doing. She always was looking at things from the woman’s viewpoint. She was interested in ensuring that companies took note of women’s needs for part-time work and helping with children and things like that and some of what she proposed has been adopted and she was a prominent figure in the Women’s Engineering Society, which was why that was chosen as the host for her award.

*What is the prize awarded for?*

Well, I said, the most… each of the scientific institutions selects the woman who has achieved chartered status that year and they select the most promising one that they have and each of them puts it up to WES and WES chooses which of those is the best one that year. So there is an event every year to recognise the winner.

*And your other daughter goes in quite a different direction then, into journalism.*

Yes, she was arts. She did Spanish, she did French and Spanish I think, yes, at Exeter University. Karen went to Cambridge and did a natural sciences Tripos. Lin went to Exeter and did French and Spanish, but decided that she wanted to do journalism and then she got into radio and then into television. And now she has more web pages than I have.

*That seems a very*...
And probably more awards than I have by now. She keeps on getting Journalist of the Year and things like that. I say, I taught her everything she knows. But I still, I find it odd, I think it probably was about twenty years ago that I was at a conference, I was chairing a conference and somebody came up to me, a young woman, and said, ‘Excuse me, but are you the father of Lindsey Hilsum?’ And I looked at her and said, ‘That’s not generally how I am known, but yes’. Since then that happens weekly, probably. Last time it happened was at the Royal Society at this Sovereign Exhibition, when a woman saw my name badge and I was talking to her, she said, ‘Excuse me, but your name is familiar’. I said, ‘Yes?’ She said, ‘Where does it come from?’ And I said, ‘Well, it’s Dutch in origin’. She said, ‘No, no, that’s not what I meant. Are you related to Lindsey Hilsum?’ I said, ‘Yes, I am’. And she said, ‘Oh, I watch her every day, she is so good’. Lin’s pleased, of course, each time.

*What do you make of it all?*

Oh, I’m very pleased. You’re obviously pleased when your children are successful. You wouldn’t know, but I presume that your parents are quite pleased that you’re successful. You’ve never asked them? Yeah, well they will be.

[28:30]

*It seems like you’ve got almost a sort of CP Snow, two cultures thing with daughters going in different directions.*

Well of course, that was right at the beginning because I married a French teacher. Betty was doing a French degree at UCL and carried on doing that, though she broadened, she also taught English and she broadened into administration later on, but she, if she’d wanted to be more selfish I suppose she could have been a headmistress and certainly she had the skills for that. But clearly she was on the arts side. I could have… I, at school I was pretty good at English and not bad at French and things, I mean and geography and history, so I certainly could have gone that way. I did win the Civil Service prize for literature, which was ten pounds. I think I was shared with two other people, that was for writing a short story and that was about 1948 or something like that.

*The Civil Service prize for literature?*
Yeah, that’s right, yeah.

*Sounds a slightly unlikely sort of prize!*  

Yeah well, it wasn’t very much. But anyway, I don’t think they have it now, but they had it then.

*How did you meet your current partner? Who I guess you’ve mentioned in passing quite a bit, but never…*

Through two committees that we were on actually. She joined the NPL committee to cover life sciences because NPL decided they were going to go into life sciences which was slightly strange, and we still find it a little bit strange because it’s hardly physics, but they think it is necessary in life sciences and there are certainly some aspects of life, of industry work there which need some measurement science. So she was brought on to the committee and at the same time she came on to the 1851 Committee, which I’d been on also for some years. I at one stage on 1851 I was representing engineering, but then they moved me to doing the experimental physics. We have Trevor Stuart who does theoretical physics and maths, but I was then and now cover experimental physics and Anne came on and that was about seven years ago.

*Who is she and what does she actually do?*

She’s Professor of Biochemistry at Imperial College and her speciality is mass spectroscopy. Now, her mass spectroscopy is way away from the mass spectroscopy I did. I did mass spectroscopy many years ago when we were looking at impurities in the elements that we used for making our semiconductors, for gallium, arsenic, phosphorus, antimony and indium. Oh, yeah, not aluminium, we didn’t do aluminium, aluminium was easy. And there we were pretty happy if we could see one part in a million, but now they measure, their mass spectrographs work in a totally different way and they can measure things with a molecular weight of many thousands and see the things in one part in a billion or something and they can follow changes in what is happening in the biochemistry by changes in the molecular weight of the compounds that are produced. It’s very complicated and when I see their pictures I’m amazed at how they can follow them through, but she is a world expert in it and travels all round on that and sometimes I travel
with her. But – and in fact she is off to Bilbao and San Sebastian later today and will be going on to Madrid on Sunday.

[33:37]
*What's her name again, sorry? Anne...*

Dell – D-E-L-L.

*I guess the one other big thing I wanted to ask you about was the Royal Society which has sort of popped up all over the place really as...*

Well, it does pop up all over the place, yes.

*What does it mean to you personally to be a member, or a Fellow of the Royal Society?*

Well, it’s obviously a great honour to be elected to the Royal Society because it’s reserved for the top scientists and engineers in the country, or in England although of course quite a few of them now work in the States or abroad. And I wasn’t aware when I was elected how valued the honour is, particularly among academic scientists, and it is regarded as being at the top of your profession if you can make it. And the selection process is very stringent and becomes more stringent as time goes by. There are more scientists around now and the number of Fellows elected each year has increased a little bit, but not much. It used to be about forty a year and now it’s probably about forty-five or forty-six, and that has to cover all of the sciences. It doesn’t cover practising medicine, but it does cover medical research and is supposed to cover engineering, though they would agree that it doesn’t really cover engineering, except that engineering is really counted as one of about ten to twelve sciences. So it’s more difficult to get in as an engineer than it is as a physicist or chemist. It has quite an active programme. I’ve been involved in various committees in time, I was on Council at one stage for a short time – well, Council membership is for a short time. Then I’ve been on various… it spends its money of course in giving Fellowships and in supporting certain aspects of science, instruments, there are awards it gives. At one stage there were industrial Fellowships and I helped with that for several years. Now I’m on the Mercer Committee, which has been set up after a donation from Brian Mercer who invented Netlon and left quite a lot of money to the Royal Society to support innovation, and there’s a committee that receives proposals from academia on feasibility of an idea for exploitation and then on the
innovation. The feasibility is a small reward; it’s 30-40,000. Innovation is quite a lot, that’s a quarter of a million and goes to really support something that is in the transition from a concept to a product. And I’ve been on that for a few years.

[37:55]

As a member of the Royal Society are there any sort of topics the Society is involved in recently that you have become interested in yourself?

Well, climate change is the one that has attracted a lot of attention and we’ve certainly got involved in that. It’s also interested in impact and technology transfer more than it did, largely because this seems to be a constant feature of research councils’ considerations and it certainly appears that there is more interest in what will happen as a result of research than of what you’re discovering, which is a bit of a pity. But that really is happening because industry is doing less itself so the academics think they’ve got to do more themselves and set up spin-off companies and things, which is not necessarily the way in which other countries function, it’s… it’s a feature of other countries. They do have things like Fraunhofer Institutes and they have MIT and companies that surround it, but that doesn’t mean to say that it is the right way to go.

What do you think, I guess, what relevance do you think to current science that the Royal Society actually has? I suppose it is 350 years this year?

350 years I think a few years ago. Yes, it was… it dates back to 1660 or something doesn’t it?

What relevance do you think it – what relevance do you think it has today to ongoing debates in science?

Well, it’s got a tremendous relevance to academic, it has some relevance to industry because it does have some industrialists who are Fellows. There are certainly some indications that it wants to really give, be more involved in advice to governments. I’m not sure that that’s right. Governments can be swayed often on the basis of inadequate science. Climate change is a very good example of that where governments have sort of, took the bit between their teeth and rushed into it instead of perhaps waiting and seeing which way it was going, because we don’t, it’s a very complex subject and we’re not sure that we’ve got our hands on it yet.
Why has this topic caught your attention in particular?

Oh, because it goes back to my own roots as an infrared spectroscopist and remember, I studied infrared transmission of the atmosphere and climate change depends entirely what happens to CO₂ in the atmosphere and how it’s absorbed and what happens as a result. So it’s a subject I ought to know something about, and I do know a bit about transmission of the atmosphere in the infrared, because that was my first papers and I still do remember them.

And what’s your view on climate change?

Oh, I have little doubt that the original estimates were exaggerated, but then the climate scientists probably agree with that now too and that it’s too complex a subject for governments to start causing economic changes because of what was originally thought. I mean I thought that… most climate scientists no longer talk about 6°C changes. The basis for it you see is that – the things everyone agrees on are that the temperature has been increasing over the last… the fifty years before 2000, and CO₂ was increasing, but of course CO₂ was increasing long before that, because CO₂ was increasing from 1850, not 1950. And if you actually look at the correlation between the increase in CO₂ and the increase in temperature, the correlation is 0.02, which essentially means that they’re not connected. If you actually select your data and look at it from 1950 to 2000, you get a very strong correlation, but then are you entitled to do that, whether you do that and say you’re entitled to depends on your prejudices. The next thing is that it is quite definite that CO₂ on its own cannot cause much of a change because the absorption band that you’re concerned with is one in quite a distant region of the infrared, around 14 microns, where there isn’t all that much energy anyway, but the peak is round about ten microns. So you wouldn’t expect it to have a tremendous effect and it’s agreed that by itself it’s a minor constituent of the atmosphere. But then you have to consider what happens as a result of the changes that the CO₂ causes. Now the CO₂ could cause a change of perhaps 0.5°C, but what happens as a result of the increase in temperature of 0.5°C and the science then says, well that could actually act as a trigger for the water vapour in the atmosphere increasing, because clearly as the temperature goes up there’ll be more water vapour coming from the water. But what happens then? Now water vapour is a major constituent of the atmosphere and certainly does affect the equilibrium between what comes in from the sun and what goes out from the earth. But the models that you have to use then become much more complicated and because they’re more complicated they’re more open to argument, which is that what will happen depends on the droplet size of the clouds, that the
increase in the amount of water vapour, if there is one, would give you more clouds, but then do those clouds keep the heat in, which clearly would give you a temperature rise, or do they keep the sunlight out, which would mean you get colder? And there are people who have said that as a result, have proved according to their own judgements, and their own model that as a result of the clouds being formed it would get cooler, not hotter. That’s unlikely, but it’s possible. And they describe it as a forcing factor, as to what would happen and the old theory was that the forcing factor could lead to a change of 6°C. I think very few people now agree with that. Some might, but I don’t think many do. They might, they think it might get up to 2°C. It depends on the size of the droplets. This is what it comes down to, if you’ve got a cloud, when a cloud is formed sometimes it makes you feel clammy and hotter and sometimes when it blocks the sun it makes you feel colder. That’s because that’s what happening. And that depends on the droplet size and the height of the clouds. So I think you would get a feel for this model being more difficult now. I mean it’s not a question just of predicting this is the amount of radiation absorbed, this is how it affects the balance, now you’re talking about really complex weather conditions as well as climate conditions. And people are saying we need more research and this is the topic of the Royal Society that we agreed we just need more research on it. Now what happened that put the cat among the pigeons was not what happened at East Anglia, which in some ways was disgraceful. It wasn’t disgraceful in the wanting to hold on to their results and not having them broadcast, because that’s something that most scientists believe. They believe that when they do an experiment and get a result, the results are theirs, they aren’t everyone’s. Of course, the trouble is, they are everyone’s, because – well, they’re everyone’s in this country because it’s been paid for by the public, I mean their salary is paid by the public, their research is paid for by the public, so clearly the results belong to the public. But, you can sympathise with somebody that feels that they have put their heart and soul into this and they have developed this way of looking at the data and these results are theirs. What you can’t sympathise with is when they say that we must stop people publishing things that disagree with us and we must ensure that they’re peer reviewed by people sympathetic to us so they don’t get through. And we must get at the editors of the journals to get that happening. That, everyone agrees, including the climate scientists, is unforgiveable, that you cannot do and that has never actually been sort of broadcast and used against them. What they were charged with was wanting to keep their results and not answering emails and doing all kinds of things that were personal and you can sympathise with them, but the business about corrupting the scientific process, that you cannot forgive them for. So that is one of the things and it’s a natural tendency that you have to resist it, because the one thing you know is that your science can be wrong and the only way in which you can hope that...
it’s right is by exposing it to the examination by other scientists. Now what put the cat among the pigeons was the realisation that the global temperature is no longer changing. That is not generally broadcast, but for the last fifteen years, more or less, and certainly for the last ten years, the global temperature has not gone up. And this data is data from the Met Office and from the American Met Office, I mean the same people who’ve been plotting the data showing it going up over the last 50 years and then suddenly it’s flattened off. Why has it flattened off? Well, it can be an anomaly, it can be sunspots or something. It can actually be that the CO₂ is now saturating in its absorption. The CO₂ is still increasing, they think, in its content, but its absorption may no longer be increasing. That is possible, it’s surprising but it’s possible, because after all, if you’ve got an absorption line in the atmosphere and you increase the amount of the gas that’s doing the absorption, in the end you will get a hundred per cent absorption over a band and you can’t get more than a hundred per cent, that’s it. In fact, what you get of course is you get two effects from any absorption band, you get the absorption at the peak of the band increasing, but you also get the wings of the band spreading out. So you might think that even if CO₂ was getting fully absorbed, that the wings of the band would also give you additional absorption, but the complication is that that band is not isolated. It is very near intense water absorption and of course if the water’s doing the absorption you can’t get more than a hundred per cent. So that could be, but of course it depends on satellite observations that you should measure this and the latest satellite observation was looked at by a very good group at Imperial College that had been doing some exceptional work in looking at these absorptions. And they said last year or the year before, that there appeared to be no or little change in the CO₂ absorption as seen by satellite. And they had various explanations for that as to how it could be. [53:35] But the point is, that all of this is coming under greater observation by scientists. There are some who still insist that this is of major concern and people have got to stop using more CO₂. Those same people also object to shale gas for some reason, even though it’s pointed out that shale gas does not produce CO₂ and as a result in the States their CO₂ hasn’t increased at all in the past few years. So you get a political complication coming in with people who essentially are against progress, in people getting more wealthy, essentially, the developed countries getting more wealthy. And they don’t like the lifestyle that has developed and they want us to be more economic in electricity and saying we shouldn’t do it. Well, they’re entitled to their point of view. There’s nothing against that. But it gets mixed up with the search for renewable energy and things, and then you get government subsidies for renewable energy and for things like wind farms. Now, the trouble is with wind farms, is not just that they sort of pollute the view, but they’re actually rather inefficient and you cannot get the manufacturers to actually give you an accurate estimate of how
much power they produce. The best estimates that people have made are that it’s probably about one-third of what people claim. I mean there are two problems with wind things; one is if the wind is too low then you can’t get any power and if the wind is too high you have to stop it because it’ll break the turbine if you’re not careful. But then if you try and get away from the pollution that’s caused to the environment by their view and put them out at sea you then have the engineering problems of is this a stable situation. Now of course you know that the oil platforms have always had problems with corrosion and there are ways in which you try and reduce it, but that’s a stable platform. The problems of keeping something moving while it’s out at sea are way worse; you’ve got to have a device which is efficient and keeps turning, and no doubt there are excellent engineers who have perfected systems that will work for a time, but will they work for twenty years. And will the forces on them actually keep them stable for that length of time. I mean what’s going to happen to their actual supports and things. So there are all kinds of uncertainties coming in that you would hope had been tested at a slower rate if there hadn’t been the political pressure that was caused by the scientific predictions, that’s the problem, that it’s not been a normal kind of progression of engineering, it’s had this pressure that you want to get rid of the dependence on CO$_2$ which should not have happened at that rate. And if you actually analyse what would happen to the economy of a country as Alan Rudge has done for the Royal Academy, it could be catastrophic in what happens to a country that tries to push these boundaries too far too quickly, because it puts its industry under a considerable factor of diminution of efficiency. You’re either going to put up the cost of electricity, which of course is not something you want to do, or you’re actually changing the way in which you develop power. And this all comes from a scientific prediction which probably was never meant to have that much effect, and this is the problem when science becomes so prominent, because science is not exact, it does rely on somebody putting forward something that may well be controversial, and then it’s exposed to criticism from the community and somebody repeats the experiment. Now, unfortunately you cannot repeat these experiments. These are not experiments which you can do in your workshop, this is on a planetary scale and is happening very slowly, but you’re trying to speed up the process because politicians want to actually do something. Then you get changes when you change the politician, the whole programme of the country has changed since Chris Huhne may have persuaded his wife to take his points. Now, should the energy plans of a country depend on that, a politician? Because he was sticking his neck out and would not actually answer letters that were directed at him by people like Alan Rudge. He just said, oh that’s nonsense, we believe in the climate scientists, when even the climate scientists didn’t believe in the climate science, they all admitted this. And one of the earliest proponents, Lovelock, James Lovelock, three weeks ago
said well, he now was a bit worried about what he had said in the past because he thought that he had exaggerated the problems. Well, that requires an honest man to actually sort of conclude that. But it’s all part of science and politics not being a stable mixture. You see, we had something like this many years ago with the Club of Rome. Now, you won’t remember the Club of Rome, but the Club of Rome was a group of economists and politicians who suddenly worked out that we were running out of all of the raw materials that we needed for civilisation and they published a thing called ‘The Limits of Growth’ which said that you could only go so fast, and they were very concerned that for many of the minerals which are required for manufacture, we had only thirty years of reserves. And it took some time before somebody pointed out that there was a good reason for that. It wasn’t that there were only thirty years of reserves, it was that no company worth its salt would worry about looking for things after they had found thirty years’ worth. I mean that was the limit. You find thirty years and say great, leave it now. In another five years we’ll look again and get another thirty years, but thirty years is more than our company may exist for, so collapse of stout party, the limits of growth vanished as did the Club of Rome.

Fortunately, there hadn’t been much involvement of scientists there, and that is the thing that really worries the people who are hesitant, I think is the best word to describe the attitude to climate science, to say that what worries us is that there’s been so much publicity going to this that if after another five years the temperature hasn’t changed, government are going to lose all of their confidence in scientists, not just in climate scientists, but in scientists and the scientific method, because it’s not understood that this is perfectly reasonable that climate scientists should strike an attitude and say this is what we predict and we must have better measurements from satellites, better understanding of the absorption of these very difficult things to measure accurately in the atmosphere, and better models. And this is a normal scientific process that we go through in refining the thing and we will see where we finish up and after some years we may have enough to be able to tell people what we believe is going to happen. [1:04:00] Unfortunately it all got out of hand.

_How much of this is a topic of – well, how much is climate change a topic of discussion at the Royal Society in your experience?_

Well, it was a topic of considerable controversy, because what happened two years ago, the Royal Society had put out a website which more or less said that people who disagreed with the theory of climate change were misled and they needed to be enlightened. That’s not quite the wording, but essentially it was like a religious document that was done by proselytes who were pushing
something forward and saying that this was the way science was and you either believed it or you were condemned. And four of us got worried about this. That was Alan Rudge, Tony Kelly, Michael Kelly and me, who in some way got together – I don’t remember exactly how – and we all said that we were concerned about it and we thought that this was wrong for the Royal Society because the Royal Society should really not put out websites like that, they should say that this is a serious matter and needs more research. And we decided to each talk to some friends and see what they thought, Fellows of the Royal Society – it was all kept within the Royal Society – and each of us contacted something like ten to a dozen friends and were astonished to discover that the overwhelming majority agreed with us and within two weeks we had forty people, forty fellows who felt that the Royal Society website was wrong and should be corrected. And what’s more, we didn’t like the way in which the pattern of the website had been designed. So we wrote to the Royal Society, we wrote to the Council and said that we were unhappy and would Council debate this and we hoped that they would agree that the website should be changed and that a method of consulting the Fellowship better should be evolved. Well, I know how I got involved because I’d got worried about this and at a meeting of the Dining Club when the President, Martin Rees, was present I had talked to Geoffrey Allen about this and Geoffrey agreed with me that this was wrong and Martin said, suddenly sort of attacked me and said, you’re wrong to really doubt the word of somebody who’s been studying this, John Houghton, for many years. And I said I didn’t know, Martin, that the correctness of a view depended on how long you had been studying something. And Geoffrey was also surprised at Martin. Martin believed in what had been written about climate change, probably still does. Anyway, when this came up and was going to Council he was a bit upset and he called a meeting the day before the Council meeting of representatives of the Group of Four, as we then were known, and the climate change scientists, which was fine. I think we had about thirty people there of whom probably twenty were climate change scientists and ten were signatories to our letter. Our letter had gone formally and had been signed by something like forty-five Fellows of the Royal Society. I mean that wasn’t the limit, I mean that was how many we could get immediately from people we knew, I’m sure we could have got a hundred in no time at all. Anyway, we were astonished because the climate scientists all agreed with us, they didn’t like the website. It was clear to Martin that the only person who backed him was John Houghton who was present, who didn’t say very much, [1:09:00] and the climate scientists all said that this doesn’t represent our views at all. So it then was agreed that the Physical Secretary to set up a mechanism whereby the website could be changed and everyone was happy. I think in the end even John Houghton agreed, certainly Martin agreed that the overwhelming majority was in favour of a change. So when it went to
Council I think it was a non-event, I mean there was no opposition to it, it was just more or less said that it’s been agreed we’re going to make this change and it was done in a very sensible way, I mean the whole thing was handled very, very sensibly. There was going to be a group that was going to include Mike Kelly that would actually look after the changes in the website, would include the physical secretary and a couple of the climate change people and they’d be advised by two panels operating independently, each of which would have a mixture of climate scientists and representatives of the signatories. They would each make suggestions independently as to how the website should be composed and then those two views, which each would be compromises, would be done by that panel. And then this was all to be done without publicity and gradually the old website would be withdrawn, there wasn’t going to be any announcement made and the new website would take its place. And that all happened without any publicity, which is what everybody wanted. I think a few months later some of the media actually got wind of what had happened. Well, you can’t have seventy or eighty people involved in something if you include all the Council members and the officers and the forty signatories, it was almost certain somebody was going to say something to somebody. So the press did get hold of it and you will find that there is some indication of what happened. I think they will try and make it more dramatic than it actually was, because in fact it represented the… the cooler side of the scientists to say basically that the website says what we know, what we have sort of a feeling for and what we certainly don’t know, and the models are sort of in that. And then it says that we must have more meetings to discuss this and we must have more research on these things. It basically was a perfectly reasonable scientific statement, there was no religious conviction coming into this saying you’re a heretic if you don’t believe what we’re doing, or any of that. It’s a perfectly reasonable website and you can see it now. And again, there have been a number of meetings going on on it and that doesn’t mean to say there aren’t people who aren’t taking extreme views, and certainly there are some people in government organisations that still are wanting to predict very large changes, but I don’t think you’ll find many climate scientists who actually think of 6°C as being something that is likely.

I guess that does bring us pretty much up to the present day doesn’t it?

Oh yeah. Yeah, it’s still happening of course. There are still [1:13:15] measurements and it will continue to happen. Then of course now we’ve got extreme weather events and is that linked with climate change or is it something – and are they extreme or is this something we’ve had before. I mean there always is a wettest month. I don’t know. Anyway, so I’m a hesitant and I’m
very interested in what is happening and if I had the time I would do some more calculations myself on this. But I think it’s a much healthier thing, except possibly the American Institute of Physics. They still are very much against anybody questioning what the international group said, though I think the international group is due to bring out something again which may well be modified from their previous predictions. That’s all right, that’s the way science works, that you get oppositions and I still know that – I think I’ve said – the paper of mine that was written that got the most citations I know was cited heavily because people thought it was wrong and if something is right you don’t write to say I think this is right and I agree with it, if something is wrong you write and say I don’t agree with it. So, and I don’t know, it may be right, may be wrong, nobody’s proved it one way or the other. All they know is that the devices work all right.

*Shall we take a short pause?*

[end of Track 24]
I guess looking over the course of your whole career as a scientist in various fields, what do you think the sort of biggest changes have been in the way that science is done?

Well, there’s much more done at universities now than there was when I started. The powerhouse for research in most countries were the government laboratories and industry and there were clearly some centres which did the more basic research, but I would say if you looked at the numbers of scientists involved, most of them who worked in the fields in which I was interested in were from industry and they were driven quite often by wanting to make devices but also wanting to understand how those devices worked. I mean when the first transistors were made we had no idea how they worked and probably still don’t understand how the first transistors worked. It was Shockley who had a theory of how they might work and then worked out that you could do the same thing with a structure that you could understand, and that led to a more, a situation where you could apply science more reasonably because you could understand the different steps. But that led to improvements in devices and led to a broadening of the research that you needed to improve those devices by going to different structures and different materials. And all of that lasted for quite a long time. Now, for some reason which I don’t fully understand, but it’s probably dealing with the financing of research, at some stage certainly in the UK, and I don’t know that it’s quite as true outside, the major industrial companies stopped doing research and there was, we can see the deficit in manufacturing industry and the government then said that we look to universities to actually improving the wealth of the nation. Now that’s the kind of statement that people can make without a lot of thought. In fact it makes no sense at all, because you know that the wealth of the nation comes from the manufacture. It may come from the finance, it may come from getting oil out, but it certainly doesn’t come from education and research in universities, that is inward. But, the vice-chancellors thought this was great because it raised their status and raised the status of the universities. And then we started really looking for universities to set out companies and things and to exploit what was going on, and at one stage I did an analysis of how much we were spending on this and I don’t think this has actually been done, that the idea was that you were going to have these spin-off companies and they were going to grow and be Microsofts and Apples and things, and when I did analysis, quite a few years ago, I worked out that we were spending something like a hundred million pounds a year on industrial liaison offices for all of our universities, so all of them had ten people working at them and they were busy getting contracts in and handling the IPR and I was actually – I haven’t covered this –
I was actually on the UCL group that was doing, I forget what it was called, the innovation or the exploitation or something, but we were doing that and in fact I worked out that the actual income to the country was something like £20 million, I think that was right. It was that order, and £6 million was in Scotland which was doing quite well through Scottish Enterprise and things, and there was a little bit in Ireland, a little bit in Wales, but there was certainly only £10 million in England, of which UCL was doing one of the best, UCL was doing something like £800K a year out of this. Well, I compared this with the amount we were getting from charities, which was something like £40 million a year, and when I produced this at a talk I was giving at some event – in UCL – I said to them, and what do you think this shows? Rhetorical question. Nobody knew. I said, I’ll tell you. It shows we’re better at begging than earning. Which did not go down well and I was immediately asked, where did I get these numbers from. I said, oh they’re UCL numbers, they come from the UCL documentation. And this was true at the time. Now of course, if you actually analyse what is happening you find that universities are doing quite well. They’re making large sums of money. But it’s all in selling the companies, it’s not in selling the products. And UCL was doing the same, I mean we were making £2-3 million by a company being set up, having some idea that the people were developing, but instead of developing it so as to lead to employment building up, and there is one example which is ARM, which actually wasn’t a spin-out company, not quite in the same way. I don’t know of a big spin-out company that has come from universities but I do know of a number of spin-out companies, certainly Imperial Innovations would say they’ve sold lots and individuals may have made themselves quite rich, but nearly always the company has sold to somebody in America or in the Far East who then developed the product, but there’s no employment coming into the UK. These are all spin-off companies and somebody’s going to realise at some stage that we’re just exporting our ideas and our talent, that the ideas are going abroad and the employment is also going abroad. So this is what the change I see as coming over the scene. You didn’t have this happening even thirty years ago, maybe not even much twenty years ago. You had Science Parks developing. Some of those were doing, they were working on a different basis, that was a company that was set up that would be near talent in the university so they could look to the university for consultation. The company would expand and it wouldn’t have the ambition to actually sell. It’s the… unexpected consequences that you get and a change in the mentality of university staff. People used to go to universities because they were interested in education and they were interested in research, they did not go to a university because they thought it was a site where they could make money for themselves. But now that must be present in the minds of many people at universities, that if I can exploit what I am doing, I can become rich. Now that is
not an academic view, or it shouldn’t be an academic view. What is more, it’s not what they’re trained for, that if somebody is interested in education and research, they’re not necessarily skilled in forming and developing a company. So you get an awful lot of them that really are going nowhere, they’re staying at three or four people and not producing anything worthwhile and very rarely do any of them make a profit. Now, I know how long it takes to make a profit from Peratech, and that was a good product, and yet it took us nine years before it started making a product. If you look at some of the records of companies that have been backed by some government investments too, if for instance you look at NESTA and you examine what has happened with their companies, you find that very few of them, actually that they’ve put money into either by taking an equity share or by giving them finance, very few of them are actually making a profit. But nobody examines the actual whole operation as a project by saying how much have we put in, how much profit or loss has come and what employment has resulted from this. Now, that’s okay, you can accept a loss if it’s led to employment because employment is obviously profitable and that’s going to actually, I mean it takes away the negative side of unemployment, that means that there’s taxation going into the government, so you’ve got to look at the whole thing, if it’s led to a lot of employment. [11:15] Now, we’re not alone in this, I haven’t dealt with all my activities by any means in what we’ve done. For instance, you talked about the Royal Society, but you didn’t talk about the Royal Academy of Engineering, and with the Royal Academy of Engineering at one stage I had to run a project from Euro-CASE, which is the European Council, I think, of Applied Science and Engineers or it’s the engineering institutions of Europe that have this body and one of the things they decided to look at was venture capital and after a time I was running it and I looked up technology transfer and various things, in fact I became viewed, because I actually wrote a few things on technology transfer and defined some of the terms, I found I was being treated as an expert in it, which I certainly wasn’t, but it becomes very easy to be considered as one. In fact, I had an invitation to go to Japan and talk at a conference on it as the European expert, which I didn’t refuse because it was nice to go to Japan, be looked after. I gave quite a reasonable talk actually. Anyway, we went to various things in Europe, obviously to look at this. And we went to Aachen and Aachen was very pleased with what they were doing in technology transfer and getting things from their academic centres, they’ve got some pretty good universities. It wasn’t just Aachen, it was the Lánde that included Aachen. We went to Aachen, I forget what that Lánde is. It’s very good and they have some very good universities. And they were talking about the methods they were using and how they had these centres where professors, who I think get paid for only nine months of the year in Germany, could set up and they got free accommodation and various grants from the government to actually
exploit their ideas, and they were very pleased with what they had done and I naturally asked them how much they had invested in this and they gave me the number, and then I said, and how many people are now employed. So they had their number, being – Germans are very good at this kind of thing, they had exactly the number, and did a quick sum. I said, so, but if you paid these people the equivalent of £200,000 a year you would have got the same result. And they didn’t like that, but that was in fact the point, that they could just have given these people grants and they would have done just as well as going through all this business of exploiting the things, they didn’t need to make anything. And that’s what you need to do, you actually need to do an analysis of what you’ve accomplished by this and we have things like the Technology Strategy Board but I don’t think they ever do a thorough analysis of what has happened as a result of being established and the money they’ve put in. And the main thing is what employment has it led to? Not, has the money been spent sensibly, I’m not arguing that at all, I’m sure that the companies have been honest and put the money in, but what has resulted? And in the end you may be sort of fighting a tide, that it may be that the general economic situation in the UK does not favour innovation and you’ve got to go much deeper and start off with what is happening in the City and the banks, which comes down to risks and things, have they got a reasonable value on risk.

[15:50]

Again, sort of looking at your whole career, I was wondering what you consider the high points to be?

Oh, obviously it was liquid crystals.

Why do you say ‘obviously’? There’s a lot of things you’ve been involved in.

Well, because the liquid crystals is one that has led – I mean we can point, we can point to people going wrong in the States in what they were doing, but what we did was right and people will probably say that quite a bit of that was due to me in the way in which we proceeded in identifying the things that we needed to do and recognising when something was the right way forward, and indeed apart from the original invention that came from Switzerland that was not actually being adopted by other people, by recognising that this was the way forward and then by working on the material and the switching elements in the transistor and recognising that we actually got good leads for the UK. Now, you can say that we let it slip, that we didn’t do the manufacture, and that’s part of the whole story, that we did start the manufacture but we never
carried it through because it needed the investment. And when you look at the investment that’s necessary, I mean Corning has put up a factory next to Sony, I think it is, that’s itself doing £6 Billion just to make the glass. I mean the glass is huge, I mean the glass is… bigger than that table when it’s got all of its leaves put in. I mean it’s seven metres or something, the pieces of glass, 7 by 3, because you need to get a number of those out…

**TV screens?**

Yeah. The bigger you make it, the more of those big ones you can get out of it. And it’s bigger than a man. That’s just the glass investment. The investment in the actual plant must be twice that. And yet the Japanese will do that, so will the Koreans, and we wouldn’t do it. Now, it wouldn’t have been that much then, but it probably would have been a £billion. And it’s exactly the same with semiconductors, that we’ve, we have no foundry for making semiconductor chips in this country now. They have one in Belgium, in Liège, which is supported by the local government there.

[pause 19:00]

Where were we?

*You were just mentioning there wasn’t a way of making silicon chips in the UK, or semiconductor chips.*

We have started, but now there’s one in Austria, there are three in France and probably the same number in Germany. Would you believe that we have no foundry in the UK for doing silicon chips. Now, of course people can buy them from the institution in Liège, which was set up by a devoted person, who’s dead now, and he got the Flemish government to support him, and he got it, didn’t rely on banks or anything. And it’s now established and is a very big organisation in Liège, in Flanders. Not even Belgium, I mean it does get some support from Belgium, but it’s a local government. In the same way Austria can have a foundry and our people can obviously buy chips from them, but we have nowhere in England which makes things. There were various things in Scotland. I’m not even sure there’s anywhere in Scotland now that is actually functioning on that level. It may make specialist things, but not the ordinary chip. And it’s, that’s what hit liquid crystals, but, the fact remains that we did get over a £100 million in royalties,
which is the biggest, it’s probably – it may not be quite the biggest ever that the Civil Service has
done, it’s certainly the biggest that the MoD has ever got. There are some pesticides which were
quite lucrative. So yeah. And obviously I got a lot of kudos out of that. I don’t think people are
so aware of what I did on semiconductors. I mean obviously the semiconductor people know, but
it’s not that obvious to people and of course quite a lot of that got outmoded by other
developments. But it’s there in the history books.

[21:30]

*Other than the general situation, I suppose, in Britain as regards exploitation of technology and
hi-tech industries, do you have any personal regrets in your career?*

Well, there are obviously things that I’d hoped I would do that I didn’t do or that didn’t work out,
that were out of time, yeah. And there were shortcuts I should have taken and things I could have
seen and I could have done quicker, but they say hindsight’s an exact science. I…wouldn’t be
sensible to think that everything I did was right and in the right order and I always made the right
decisions, no. No, I’ve been pretty lucky actually in that some of the things that I wanted to do I
couldn’t do and it turned out to be pretty awful things to have tried. So yeah, I suppose if I wrote
down everything I had done I would see some things that I think I could have done better or that
other people could have done better, but generally it’s not been too bad.

*What do you think you’ve actually enjoyed most about the sorts of jobs that you have done?*

Well, I think mostly you get the enjoyment by looking back at it. You certainly enjoy what
you’re doing otherwise you wouldn’t do it. You get carried away by it. I regret certainly some of
the things that I neglected in the family because I was essentially driven by what I was doing and
I suppose that was quite selfish and is selfish with many scientists and engineers who get
enthralled by what they’re doing. I think I said that I, after my wife died I regretted this and
talked to my daughters and they said no, they knew that that was happening but they got lots of
benefits of what was happening as a result, in travelling and seeing other people that they
wouldn’t have been able to see. So you can’t go marking your life in that way.

*What’s the interest, what’s the source of interest in this? Bearing in mind that I’m not a…*
Curiosity. Always, you have the kind of mind that you want to know the answer to questions. You see something and you think, how does that work, or what would make that work better. Scientists are very different in what they’re doing. I have great problems in understanding the emotion that people feel about the Higgs boson. It would leave me completely flat. I want things to work. I do have, I suppose, quite strong views about the debt you owe to the community. In the end people forget that the community actually pays for them to do what they’re doing when many of them say well, they would actually pay to do it if anyone wanted them to. But they don’t, I mean the community pays for you to enjoy yourself and when you consider what a number of people go through who aren’t as privileged, you should realise that you do owe them something, so you should always be concerned with what are you doing that helps the community. I mean when I look at that TV I can see that it adds to the enjoyment of a number of people. Well, you can argue that it doesn’t need to be a flat panel, they could have seen the old thing, but I realise that these screens go into many homes and are much more convenient and probably cheaper in the long run than the cathode ray tube. You can’t have a cathode ray tube that big. And the same goes for some of the semiconductor things, that essentially the community benefits from it and you regret that it’s not benefiting more in the employment that it would give. So you should have some kind of conscience about what you do and of course you have a conscience about the people who throw their lot in with you, working with you and for you, and you want to see them actually enjoying what they do and feeling fulfilled and seeing that their talents, which of course are each different as individuals and they’re certainly different from yours, that they’re recognised and they’re allowed to exploit them. And it does give me quite a lot of pleasure that there are very few people who have worked for me and with me who don’t actually still have a good relationship with me and want to talk to me and really have enjoyed their time. And I still get people coming up to me at gatherings, the Royal Society and the Royal Academy, and they want to say hello and say how much they enjoyed working with me and what’s happened to them as a result and they give me a lot of credit that I don’t deserve, except possibly in giving them an opportunity. [28:30] And I had a woman coming up to me the other day at the Royal Society and saying, oh I always wanted to meet you because for seven years I worked on transferred electron devices and I was thrilled as to what they could do. And I said, ‘Well at least you called them the right name, you didn’t call them Gunn diodes, that would have really irritated me’. That’s one thing I do regret, that the damn thing was called a Gunn diode instead of a Transferred Electron Device. But still, these things happen. So that’s it, I think. That’s the way I work.
I guess my final question really is how you’ve found doing this interview, which I guess this is session number eight by my count?

Surprisingly easy. One of the things that you recognise as you get older is your memory does fade and there are some things I certainly can’t remember. I can’t, I mean I see faces and I can’t remember names. I also can’t remember programmes I have watched or films I have watched. Anne reminds me that we saw this programme, I can’t remember it, I’ve seen it, it just doesn’t stick. And I thought that would happen with thinking of events and things, and I have needed to look things up to check on dates and things. So I was very surprised with how long I’ve worked for CDT, for example. I thought it went by in a flash, I was amazed to discover I’d worked for them for five years, that’s amazing. But it’s a fact, I know, because they paid me so I could see it in the accounts that I had been paid by them. And there are other things that suddenly sort of had come to life, looking up conferences and things and the interactions with people. But I found it relatively easy and okay. I’m surprised that anybody should want to actually, I will be surprised if anyone wants to go through it for all these hours, because that’s the trouble, it’s so long. Unless you were going to sort of abbreviate it and cut it down.

No.

But it’s there, it’s been done. So there we are.

Good.

Now, this is nothing to do with it, are you still interested in seeing, in me getting the intruder alarm working?

That will be brilliant if you could.

Yeah, all right. Well, I will persevere with the Chinese or the Hong Kongese or the Taiwanese or wherever – I think it’s Chinese – getting a radar set, because as I say, I was quite surprised to see this thing doing that and I have had to look at all the individual bits, which are mostly okay. I don’t think there’s anything that’s really broken.
Good. Cyril, thank you very much indeed.

[end of Track 25 – end of interview]