The Royal College of Physicians and Oxford Brookes University
Medical Sciences Video Archive MSVA 167

Sir Martin Wood OBE FRS DL in interview with Sir Rex Richards FRS
Oxford, 10 June 1997, Interview I

Part Two

RR Martin, at our last recording we reached the stage where we were talking about the design of the high resolution superconducting magnets for NMR but, of course, during this time when the work on these magnets was going on, you had also been designing and building a dilution refrigerator which would enable physicists to work at a range of temperatures from four degrees down to some very low temperatures. Would you care to talk to us a little about that? That started in the early sixties?

MW Yes, it started in the early sixties. It started as soon as superconductors came along because we had to provide the low temperature environment for the magnets. For several years we continued to benefit from the Clarendon Laboratory, which let us sub-contract the manufacture of the cryostats to the low temperature workshop and indeed the electronics too. We made the magnets, the Clarendon made our cryostats to our design and so on and the power supplies for energising and controlling the magnets. Because of the difficulty of obtaining and using, and the cost of liquid helium, it was very important that the cryostats were very efficient and could be cooled down quickly and efficiently. One therefore used the minimum amount of helium. We actually put a lot of technical effort and design and thought into cryostats. This is a slightly strange story, but you will probably remember Heinz London, one of the two famous London brothers. There was Fritz London who made some of the very early discoveries and concepts about the phenomenon of superconductivity and his brother Heinz was very interested in low temperatures. He predicted in, I think, 1952 at one of the earliest low temperature physics conferences in Oxford, the possibility of developing a cooling technique which involved diluting helium-3 (^{3}He) into superfluid helium-4 (^{4}He) on the principle that if you had an interface between the two liquids, if helium-3 could be dissolved in helium-4 which was a superfluid at these temperatures, it would be like a gas evaporating and you’d have a cooling effect which went with it. Harwell then set out to try and develop equipment which would show this. They had considerable difficulties and the DSIR was very interested in developing these refrigerators because a lot of physics could be done if one could go down from 0.3 Kelvin which was the lowest you could get with pumping helium-3. He set out to form a contract with somebody or other to develop a helium liquefier and we got a letter asking if their contracts man and scientist could come over and see us in Oxford when we were in 27 Northmoor Road. We hadn’t moved out, we were still in the shed at the bottom of the garden. They came in and I always remember these two smartly dressed people sitting down in our sitting room saying that they were considering three companies, Arthur D. Little, Philips of Eindhoven and Oxford Instruments as if we were all in the same bracket.

RR Did you show them the garden shed?

MW Well, I said to them, 'Fine, yes, we'd love to do this,' and they were actually very keen to do this with a local company over which they could have some control, so I think they must have realised that there was a little bit of humour behind this. But, they were very keen to do this with a local company; we could do the manufacturing that they could keep a watch on. I remember Audrey sort of winking at me and then she disappeared out of the room and the way I was sitting I could see her going down the garden path with a broom over her shoulder to the shed to give it a sweep out, because I'd said that I'd take these people down to the garden shed. Anyway, we did take them down to the shed and we got the contract in the end and here is one of the early products. We won't go into all the details about it, as you know, it is a series of heat exchangers and the bit at the bottom which ultimately was cooled down to about 20 millidegrees, I think this one went...

RR So 20 millidegrees from 4 degrees. I mean, it's a tremendous temperature drop really?

MW From 0.3 degrees. We had a helium-3 bath which we pumped to 0.3 which was here I think. There's the thermometer on it and that went down from 0.3 degrees through these copper powder heat exchangers to what was called the mixing chamber, where you had the helium-3 and helium-4. Below certain temperatures, they actually separated out, like oil in water separates out, with the helium-3 on top, being the lighter isotope and moving through the boundary into the helium-4 and cooling. The bottom part was where you screwed your sample or whatever.

RR And this was developed into a commercial machine which you could just sell like a refrigerator to physicists?

MW Absolutely.

RR And I believe you still manufacture these?

MW We still do. I mean, it taught us one of the strange, probably illogical, lessons of business that they're very difficult things to make. They've got every conceivable cryogenic difficulty, superfluids, helium-3 and this, of course, is just the core of the huge masses of pipes and tubes. Every single joint has got to be leak-tight. If we sold one of these to Osaka University and they get a leak on it, think what it would cost, in the confidence that the customers have in us and in money terms, to put that right. We had competition once. An American firm started up making these things, a firm called SHE, Superconductivity Helium and Electronics, I think, and they called it SHE, but basically it's a very difficult thing to make and there isn't a great demand for them, but it's gone on and on. There was a time about ten years ago when orders began to dry up and we were about to close down production altogether when, having virtually decided to do this, orders started pouring through the door. I don't know whether this is a real lesson. We always sort of think, you know, that if you want to stimulate orders, let it be known that you are closing down making a product. We make, I don't know, about four or five a month now.

RR Really? And am I right in thinking that now it's so automated that you can just dial up 15 millidegrees or 25 millidegrees?

MW Getting close to that, yes. Because apart from the cryostats, there's quite a big gas handling system and that's all automated now and computer-operated.

RR So that has been a regular earner?

MW It's not only an earner in its own right, but since all the various particular discoveries in physics, the discovery of the quantum Hall effect and the discovery of HT (high temperature) superconductors. Certain physical things suddenly make people want to work...

RR And look into things more carefully, yes.

MW The phenomenon you are studying depends, for instance, on the relationships of magnetic field and lower temperatures. Sometimes it's much easier to lower the temperature than it is to increase the magnetic field if your answer depends on that ratio. I mean, since we started making refrigerators, we've reduced the temperature which you can operate by an order of three orders of magnitude approximately, whereas we've only perhaps doubled the magnetic field. So, from the point of view of the experimenter, it's one of the most important things we've learnt.

RR So this is perhaps a very important and influential development although it is only of interest to a small number of people?

MW It has another effect. It has, as I have said, got every considerable cryogenic manufacturing difficulty involved in it and if anybody is ever in any doubt as to whether we can make anything they want us to make like a magnet, then we take them down to the helium dilution refrigerator department and say we make this, and they say, 'Well, if you can make that...'

RR Well, if you can make that, you can do anything!

MW Yes.

RR Right, well if we could go back to the first superconducting NMR magnet, I remember we had terrible problems with the cryostats which were sometimes liable to oscillate and they made noises like an organ pipe and boiled off the helium at a tremendous rate and we had all sorts of accidents which are deeply engraved in my memory. I remember a wonderful engineer that you had called John Rackstraw working with you who very tragically was killed in a motor accident, but I had a great admiration for him. I see you have brought with you a piece of stainless steel tubing and perhaps you would like to tell us the history of that, because that comes from the time when you were designing better cryostats, wasn't it?

MW Yes. Well, particularly with NMR, cryostats are important because these were running and left on indefinitely, day and night, week after week, so the helium consumption was very important. Unlike that copper magnet this is quite light, this is very thin stainless steel. It's part of one of the shells we had inside these steel thermos flasks. We tried to explain them as thermos flasks because just as you keep coffee hot you keep helium cold, and instead of glass, because glass is dangerous and impractical to build on a large scale, you use stainless steel. Incidentally, the first cryostats we sold were all built in the Clarendon Laboratory. We made the magnets and we sub-contracted the manufacture of the cryostats and the electronics back to the Clarendon Laboratory who did a fantastic job for us. Using traditional methods, you tended to use brass and copper for the cases for it, but we went over to stainless steel and eventually fed the stainless steel technology back to the Clarendon. What I think is rather a beautiful piece of steel here came when we had an accident. There was a vacuum in fact on each side of this, inside the cryostat, and something went wrong, you got a lot of pressure outside and it imploded and spontaneously went into that shape and this was sort of thrown out onto our scrap dump. I always used to go round that and my house is littered with odd bits of things which I think are rather beautiful that come off our scrap dump. I mean, all the doorstops in our house are coils that have gone wrong and been sawn up.

RR Well, now I can remember in those days the cryostats that we had used to boil off about 200 millilitres of helium an hour, and I saw down at Oxford Instruments not so very long ago, a cryostat which needed to be filled only once a year. That just gives an idea of the incredible improvement in the engineering.

MW It's not only the cost, it's the bother and now it's particularly true when you get industrial applications. We might come onto them later, but let me say that we have now recently installed a magnetic separation plant one thousand miles up the Amazon, run in the sort of horrific atmosphere of a mining community. And there's this very large magnet, ore separating magnets, for taking a small iron impurity out of china clay. I think it's got a bore of about sixty centimetres compared with the magnets you're talking about and again it's only filled up once a year.

RR Is it really?

MW Yes.

RR It's an astounding engineering achievement, I think.

MW You can say that, or you can say that in the early days it was just very crude. I mean, we have moved a long way from it.

RR Yes, but you have to bear in mind that the latent heat of evaporation of helium is extremely tiny and so it doesn't require much energy to boil all that helium away.

MW You're opening up quite a big subject here because I mean if we can jump a little bit, you mentioned that ten years ago high temperature superconductors, which operate up at liquid nitrogen temperatures arose. One of the great advantages predicted for that was that they were going to be much cheaper to operate because they operated at higher temperatures, for example liquid nitrogen is like the price of milk and helium is like the price of whisky or something, I don't know, these sorts of comparisons. However, the high temperature superconductors have got a lot of material difficulties in themselves and we spent thirty years working on the cryogenics which you were talking about, and it was so important to us to make the cryogenics efficient, easy to run and so on, and we've been tolerably successful. However, actually raising the temperature up a little bit, it helps, but it's not such a big thing and as of this moment, we've had high temperature superconductors around for ten years and nobody has yet sold us a high temperature superconducting magnet. It will come, we're very optimistic, but it's the work we've done on the cryogenics in maintaining low temperatures and using very little helium that's actually made a lot of difference to the development, not only of research magnets, but for the industrial application of them too.

RR Quite. Well, now perhaps we ought to go back to the high resolution magnets for NMR. You built a magnet for my laboratory which had a magnetic field that corresponded to 320 megahertz for protons, but the bore was rather narrow and at about that time I became involved in the Oxford Enzyme Group and we had quite a lot of money to develop new NMR equipment...

MW When you say 'became involved with...' that's a euphemism for saying you started it and got all the money for it.

RR I was very much concerned with it, yes, and so the question was should we be building lots more equipment? We were very interested at that time in the possibility of having a commercial company to build the equipment rather than for us to have to spend the time on it. We had discussions with the Bruker-Physik which was a very good electronics and NMR company working in Germany, and I remember a discussion in my dining room in Merton College with you present and Professor Laukien, who was then the owner of Bruker-Physik, and some of your engineers in which we discussed how this could be done because they had no experience of superconducting magnets. Their equipment was designed to work at 90 megahertz, so we agreed that the sensible thing would be for you to manufacture a magnet just like the one you had built for me, but with a slightly bigger bore and a lower field, so that it would work at 270 megahertz which was three times their standard 90. That was agreed and you manufactured a whole series of very successful magnets working at 270 megahertz and Bruker sold them all over the world, didn't they?

MW Yes.

RR So that must have been quite a change for you because you'd been manufacturing special magnets for individuals and here was something which was a commercial proposition?

MW It was the first time that we'd sort of got involved in batch production, serial manufacture altogether, yes. I mean, that story went on, as I think I mentioned, you developed and came back to us for higher field magnets and we worked very closely with Bruker. They produced the consoles and did the marking of this business and jointly the whole business of NMR spectroscopy really grew into quite a...

RR Yes, and Oxford Instruments developed and you pushed the field up to higher and higher values. Have you got an idea of the scale of that high resolution business?

MW I'm trying to think how many magnets have actually been built. It's become a separate company altogether now, making NMR magnets, because the concept and the way of thinking about your manufacture is quite different from the one-off business.

RR What's the order of magnitude? Have you any idea? I mean, you must have made, what, 1,000 magnets?

MW Oh, many more than that, and we're now just completing a 900 megahertz magnet. We were asked to produce a gigahertz magnet, but we said that was really pushing beyond the technology of current materials. I'm sure it will come. We're working on such a thing, but you have to do that for some time before you can actually make a fixed price contract with someone for selling it, so we said we would be happy to do 900 and we're just about there now.

RR So that is a kind of regular and continuing part of the business now?

MW Yes. It's a part of the business which, I must say, gives me a lot of pleasure in that it's not only an interesting technology you're pushing things to high fields and high homogeneities. What Simon didn't push for was high homogeneities, for some reason, I hadn't thought about that, but he didn't, but we're pushing for the highest homogeneity, the highest stability and time ...

RR You're talking about a few parts in 10^{10}. I mean, it's an astounding engineering feat.

MW Well, this came from developing the Golay coils taken...

RR But it's also the engineering of the solenoids and everything. Now, this was all done with filamentary wire, wasn't it? Perhaps we ought to talk a bit about it.

MW No, it was all done with single core wire, the early ones.

RR But, as you moved on to higher and higher fields, you came into the multi-filamentary wires, didn't you?

MW Yes. The problem is the question of joints there, but if you've got a single core wire, it's quite easy to make a welded joint and make it absolutely superconducting right through the joint, which you need to do if you are going to have a magnet which you set into a persistent mode and the field doesn't change over months. When you get to multi-filamentary materials, I can show you some examples here, but...

RR Perhaps you could explain, do we understand why the multi-filamentary wires are superior at the higher fields?

MW Well, there are several reasons. If I can just show what they were like first, then we can explain afterwards. The final product is a wire, which just looks like copper wire really, and in fact there are many different types of this in slightly different sizes, even some rectangular shapes. This is just one piece of superconducting wire. These are niobium-titanium we're talking about here, and if that was a single core, you would take a billet of copper, put a niobium-titanium rod into the middle of it and then just draw the two out together, so that a thing that starts about that size may be twenty centimetres in diameter and fifty centimetres long. Fortunately, the mechanical properties of those two metals are such that they draw very well together and weld to each other and then, as I say, you've got a single core and you can join them easily. However, if for any of a number of reasons, the superconducting part of that wire goes normal, that becomes resistive and there's a complete block. There's no superconducting path through it, so it tends to spread and the whole system breaks down. If, however, you divide it up into a lot of filaments, so that the current is going down thousands of filaments instead of just one small filament or one big one, then if one of those goes resistive temporarily, it doesn't matter. But, there are other reasons to it. Actually, they work rather better when they're in fine filaments in close contact.

RR So how is this made?

MW It starts off in the same way where you take a billet of copper and you drill a series of holes, perhaps one hundred holes, through it with something like a rifle drill perhaps two centimetres in diameter. Fill them up with rods, work with a copper plate each end welded on and then draw that down, so you've got initially twenty filaments in a billet of copper and you swathe that down, you don't draw it down. Initially you screwed it down. When you get to a certain length, then you take it out and you chop it up into, perhaps, bits about sixty centimetres long and put those into another cylinder and swathe that down again. And when it gets to that length, you chop it up again into another cylinder and draw it again, so that eventually you get more and more filaments into it. That is the early stage where you've got the thick rods there, in this copper block and it looks rather a nice object like that because this is the end that you have to chop off before you go to the next stage, but you can see the blocks of niobium-titanium inside there. And this is at a later stage where, it's a bit difficult to see there are probably a couple of thousand filaments all over there and this is ready to draw out further again...

RR If we put that down so that it shows in that direction, maybe we can see it.

MW Right. And then the final product. I've got a piece of this wire in which I've dipped this into acid to etch the copper away and you can see that inside are just lots of filaments. There are several hundred filaments there. There are many different kinds; there are some with thousands of filaments. What started off as a simple technology as here, just this one superconducting wire, has now developed into a very complex technology, and these things have different numbers and they have other elements thrown in too to help in different ways. But that is the conductor that we use and carries now much higher currents than the single core material used to. This makes the contacts much more difficult...

RR Much more difficult to make the joints. There's a lot of know-how in this?

MW Yes, and in fact there were some people at Harwell who were working on this and we gave Harwell a contract for developing these joints, which went very well. We were working on it too, I think they got there first actually, but it became proprietary knowledge. Two interesting points here. First of all, the benefit of having big, very sophisticated, competent laboratories on good relations nearby, so that when we get into trouble we can get hold of assistance from other people. We still use that the whole time, but one slightly unfortunate aspect of the story was that one of our engineers who was working on this was by-passed for a particular senior job...

RR For promotion?

MW For promotion. I mean, this happens. We had a senior job going and several people applied and one of the people who applied who was not given the job felt a bit upset about this and left and went to a competitor, which subsequently was in some financial problems and sold some of their niobium-tin technology to the Japanese for millions of dollars, which we had actually generated through this contract with Harwell. But, that's life.

RR This is one of the hazards of innovative enterprise, isn't it?

MW Yes.

RR Well, now you've mentioned niobium-tin, that presents special problems, doesn't it?

MW Yes.

RR Can you just explain what they are?

MW All superconductors present special problems! There's a nasty sort of law and I'm not sure if it's really true, that the better the paper performance of the superconductor, the more difficult it is to use. I think that applies almost completely with all the superconductors that we used. Niobium-titanium is one of the nice and tactile, easily handled materials. You can bend it, unwind it, and it works just as well. Niobium-tin is extremely brittle. It's what's called an A15 material and they're all very brittle materials. The atomic configuration makes them very brittle, so you cannot pick a wire like that and bend it. Bending it into a coil fractures it right inside so that it doesn't work. In the early days, one or two firms made very thin film material that was only about one-tenth of a millimetre thick, so that one could actually bend the strip up. In fact, our first 10 tesla magnet was made with that strip. Nowadays, what we do much more is use material in which the niobium is embedded in a bronze matrix, not copper.

RR It would be like this, wouldn't it?

MW It would look just the same, but actually in bronze...

RR This would be bronze and the little pieces here would be pure niobium.

MW Yes. That was another reason for the filamentary. Because niobium and bronze are tactile, you wind it into the form you want and when it's all ready you raise it to a temperature somewhere around 800 degrees for some hours, and the tin migrates out of the bronze and into the niobium and forms niobium-tin, so you finish up with niobium-tin filaments in the position required. I'm not very proud of this one, but it's actually a niobium-tin magnet. The problem here is, of course, then you have to have the materials, the insulation and everything that will take the high temperature you have to take it to in the curing of it.

RR And if anything is wrong with it, you just drop it.

MW Makes another doorstop!

RR Makes another doorstop, yes.

MW We've got lots of them! It's a fact. It actually leads to good discipline. You've got to get your technology right so you don't have too many failures. If you say that if you unwind a coil it costs money, you don't want to unwind coils. But if you absolutely have to throw it away if it goes wrong, it makes you even more sure that you get it right first time.

RR Now, this brings us up to the early seventies when you had a bit of a crisis of management in the company and Barrie Marson came along. Shall we talk about his arrival, because he was a very important person, wasn't he?

MW Yes. It's always been part of the ethos of Oxford Instruments that it's controlled and run and all the decisions are made by scientists and engineers. It's often said that scientists and engineers can't read, write, talk or whatever and there may be many who cannot. But there are quite a lot who can and to have one or two people, in fact, at the top like Barrie Marson who was superb on these things and will train other people and be a role model for younger people to learn to perform, both financially and in management and everything, as he did, is very...

RR But he came in as the chief executive, didn't he?

MW Right. He came in as chief executive and was extremely useful to the company. We were about just over one hundred strong when he came.

RR And you were the chairman of the company then, were you?

MW I was the chairman of the company, yes. I was chairman from the beginning until we went public. He came in as the chief executive from a bigger firm. The troubles we'd got into were really because the early management team, which had been superb during the early years, liked and were good at operating in small companies and it's quite different when you get bigger.

RR So you were growing very fast?

MW We were growing very fast. I've got a curve, which I was showing you before, of the growth of the company over the years and to get the whole curve up to the present day on one piece of paper...

RR You had to use logarithmic scale, did you?

MW Well, if you're talking to some people, they don't like you using logarithmic, they don't quite know what you're talking about, so I was using a normal scale and for the period from about 1962 up until when Barrie Marson came, I think we hardly lifted off the bottom line and yet the figures show we were growing I think at 90 per cent compound per year. We were small, so that growth doesn't show much on the curve, but that sort of growth...

RR Is very hard to handle.

MW ... very hard to handle. In fact, it was handled reasonably well, but it just ran out of, I suppose in a word, management ability at the end, both in terms of maintaining all the sort of cost controls and the inventory, all these things which in a very small shop you can walk into and you can see. Barrie came in and changed all that very quickly and got us back on a line of predictable profitable growth which went on for all the time that he was chief executive, 14 years I think, through all the periods of real growth you are talking about through the NMR business.

RR Now, I know that you've always been very keen on the employees having a share of the company. When did you really begin to introduce that on a major scale?

MW We've always been very keen. We were a little bit reticent at the very beginning in suggesting that our employees should put their hard earned money into shares when it was all a bit of a dicey operation. It was when the ICFC [Industrial and Commercial Finance Corporation] came in, l967, that we were very keen then because in principle we were more stable, albeit there were annual problems, materials and money and so on, but we had got a momentum and it was going to go then. We were very keen that our employees should join in the potential capital gains of the company and in the benefits of the growth of the company, and we made various schemes available to all employees in the company so that they could buy shares in the company. These were in quite small blocks. People honestly didn't know much about shares in those times and Audrey had developed a number of talents which she didn't expect she had in the early days, I'm sure she'd be the first to say so, in terms of company structure, organisation, the legal side and the financial side.

RR She played a very important role, didn't she?

MW An absolutely key role. I used to do the manufacture and the design and the sales and she used to show all sorts of talents in the way of...

RR I remember you telling me once, that the key feature of starting a new company was first of all to marry the right wife.

MW Absolutely, yes. She was the formal company secretary and she organised the whole of the share structure in the company right until about a year before we went public. There were a few funny stories like people not being too keen on spending money on a piece of paper they didn't really know the point of and Audrey saying, 'Come on, you've got to do this,' and they said they hadn't got the money and so she said, 'Okay, well, you won't have to pay. You can pay 10p in the pound now for it and the rest sometime later,' and she'd find a way of getting the shares all round the company. And there was certainly one case I remember of somebody coming back when there was the first placing of shares later and they were worth quite a lot and he was very upset, he said he couldn't find this bit of paper he'd just stuffed in the back of drawer somewhere. He didn't realise that one of the jobs of the company secretary was to keep a register and you could get copies of these things, and when he found out that that piece of paper was worth about as much as his house was, you know, these things became very important. It was true that we developed a sort of ownership culture, if you like, whereby people...

RR It's been a great strength in the company?

MW It's been a terrific strength. Of course, the people who had shares at the beginning had the biggest financial benefits, but even the people who take shares now and every year everybody does, it's part of the sort of bonus scheme of the company that it's paid in shares, so that a high percentage of the people in the company are shareholders and get the annual report and all that, and even though the people who perhaps have taken shares in the last few years haven't made the same gain as the others, it builds some sort of...

RR It builds a loyalty and an identification.

MW ... an identification, yes, because they see everything, all the accounts and all the goings on and the company have to report it every year. These are just stacked up on the benches and everybody sees a copy of them.

RR Now, of course, during the seventies when the high resolution NMR business was ticking along very nicely and you first of all made the 470 megahertz magnet, that got a very prestigious award in America, didn't it?

MW Yes.

RR An award for the best in engineering achievement and then of course you won the Queen's Award, didn't you, on two or three occasions?

MW Eleven.
RR And that started back in the sixties, I think?

MW It was for a NMR magnet. We got the first award in the late sixties, wasn't it?

RR 1967. So that must have been good for the company?

MW Yes, it was. I think the first one was very good. They were all good. The first one was good without any question about it. We had a good party and the bank manager thought it was fine and so did the customers. It was great. It was a sort of outside verification of the credibility of the company somehow. We got a second one soon after. By the time we got the third one, I remember our bank manager sending us an article saying that the companies that got Queen's Awards tend to go bankrupt more than others, because they're spending money on advanced R. and D., and that wasn't a very good prognosis for being commercial. So perhaps the banks were slightly less happy for a few years. However, the last few Queen's Awards we've got, they've joined in and I think they recognise that Oxford Instruments is going to be around for a year or two and they've joined in the party. Very nice for everybody else. It's the sort of party where the wives and families come in.

RR And it makes them feel proud.

MW Yes.

RR Now, of course, in the early seventies too after Barrie Marson's arrival, Oxford Medical began to get off the ground?

MW Yes indeed, there's a little story behind that one.

RR Now, how did that come to be?

MW Well, going right back to when I said we were interested in starting a medical company, we found that such were the difficulties of making superconducting magnets that the whole staff, the technical staff, the management and everybody was absolutely focused on making magnets, designing magnets, making the ones we'd made tested and working and so on. Introducing anything else was very difficult, but we did introduce one or two medical ideas. In fact, I've got one here. This is one device we made with help from the Clarendon Laboratory, and you may remember the administrator at the Clarendon Laboratory, Dr. Croft, who lost his sight in the end. He advised us and we talked to his medic that it was much easier to remove cataracts with a cryogenic device than it was with forceps under anaesthetic. This is a little nitrogen cryostat, if you cool that down, the tip here gets cold and you can remove a cataract.

RR Was that the very beginning?

MW No. That was one of about three or four ideas that we latched onto. There were several devices.

RR You had a device for pills, didn't you?

MW We had a device for dishing out pills and there were several devices. We found that the doctors love to go down in history with their name attached to a device and you've got to be extremely careful when a doctor comes to you, or anybody in the medical profession, with something that is absolutely world-beating. If you research it, you'll probably find there's ten others very like it all called after somebody else. You've really got to research it out and see that it's right. So there were several false starts that we made, partly because the potential product we chose was really not marketable in the long run and, secondly, because we didn't give it enough attention inside the company. In 1968, in desperation after two or three attempts at getting a medical business going, I said to a friend who'd just graduated in physics from Sussex University, 'I'll give you two years salary, I'll put you in a room with a telephone and you see if you can pick up something that could be developed in the medical business.' This was right outside Oxford Instruments, and he in fact went back into the slaughterhouse up in Middle Way, so we were actually there longer than the main company. Most of the company had gone out, but the rent was so low that we just kept it on for odd little projects like this. And he made it his business to go round all the medical departments and the hospitals in Oxford and within three months he was in the Churchill Hospital talking to Dr. Frank Stott - maybe you know him?

RR I do, yes.

MW Who had developed a miniaturised recorder for measuring any physiological parameter, primarily...

RR A portable thing rather like a Walkman, wasn't it?

MW Yes, it was about that size, quite small, which took an ordinary audiocassette and he was doing it for cardiology...

RR ECG [electrocardiogram].

MW ... and also you could do EEG [electroencephalogram] and he later produced a blood pressure one, an invasive blood pressure system. He said he'd developed one and he now wanted a dozen made, I think. He was bored with repeating the thing. He just asked us, the development had all been done, and could we make it and before we'd made half that twelve, some other MRC laboratory heard about this work going on in Oxford and they wanted twelve. It absolutely mushroomed, this business, and I think actually Audrey was the first person who saw the potential significance of this, which was that instead of taking a sort of snapshot of the situation of your heart or your brain or whatever at one moment in a hospital on an elaborate machine, you've got a sort of 24 hour continuous recording. We built this up, albeit slowly, in Middle Way until about 1972 when Barrie came - he was not a magnet technologist or a cryogenic expert...

RR But he was an electronics man.

MW ... but he was an electronics person and he said he would like to have another leg to the business, so that if something happened to the market in research equipment or in magnets or whatever, there'd be something else there. And we had an electronics business then for making the electronics for the magnets and the cryostats and he said that he was looking around for something that he could make in quantity which was more like he had made, in principle, before he came to us. Audrey and I had the choice of either diving in with effort and time and money in developing what was then called Oxford Medical Systems Limited, I think, in its own right or we thought here's the opportunity, let's put it back into Oxford Instruments. So we actually opted out of Oxford Instruments for about four years, got something going, and then fed it back in again. Barrie took it up and now it's a major part of our business, with several other products too, but the ambulatory monitoring is the core business.

RR Well, whilst all this was going on, of course, there were people, particularly Peter Mansfield at Nottingham, who were developing what has now come to be known as magnetic resonance imaging and this was a technique which required...

MW With John Mallard in...

RR And John Mallard in Scotland, in Aberdeen, and Paul Lauterbur in America. This required, of course, magnets large enough to put a whole patient in. They naturally enough came to you and you, first of all, started building some ordinary non-superconducting magnets, didn't you? But as the technique improved and they began to get images of quite extraordinary power, it was obvious that the sensible thing to do was to go to higher fields and build superconducting magnets. These were on rather a different scale from anything you'd made up to now, I suppose?

MW Yes. Yes, they were. They actually started off doing images in the sort of magnets we've been talking about, NMR; they brought down lemons and grasshoppers...

RR Worms and things like that.

MW ... and mice and put these in these magnets. We looked after them very carefully and they got images and were sufficiently encouraged, then, to go to a larger scale. Well, developing a superconducting magnet of that size, with its cryostat and all, was a pretty expensive business.

RR Yes, it must have been a huge gamble really?

MW It would have been, but we developed the resistive ones first. We actually used aluminium foil; it's going back more or less to this technology. It was a flat strip, it was actually about twenty centimetres wide, quite thin, and anodised aluminium so that it was already insulated. We bought this from the milk bottle top people and wound this up and cooled it on the edge. Initially, we didn't have to put much heat in, nothing comparable with that, and so we wound these big pancakes. I think they had a bore of something of this sort...

RR About fifty centimetres, I would think.

MW Something like that, yes, and wound with flanges which were cooled. These coils were edge cooled. The homogeneity wasn't as demanding as the spectroscopy business by several orders of magnitude, but because the coils were big, actually it was homogeneous over a fairly small volume in the middle, we made several of those. And, again, it built up very quickly because they very soon saw that they really were getting good images of soft tissues and so on, and the pool from the medical market was absolutely incredible. Absolutely fantastic. All the big healthcare companies in the world joined in immediately, you know, Johnson and Johnson, GEC, Toshiba, Siemens, Philips, the lot, and we were the only people who made them and we very quickly developed a large and rather inefficient magnet, looking back on it, because the demand was such and it just had to work, so we over-designed it.

RR The scale is rather intimidating when you see these huge tanks?

MW Yes, yes. But, I think the companies were willing right at the beginning to waive all sorts of problems about safety and so on, which had to come in later. All the materials we made and the tubes we used had to be certified and tested before we used them and so on. With the very first magnets, we were a bit more easygoing about that.

RR But, this raised a very big decision for the company, didn't it, because in order to manufacture these magnets on a significant scale would have required a huge investment, wouldn't it?

MW You said 'big decision' - I don't think it took us long to take it!

RR Well, you had to!

MW Yes, it was absolutely what we were looking for, if you like. I mean, we recognised then that the growth of the business restricted to research magnets was bound to be relatively slow. It was steady, surprisingly steady, over the years. I mean, Barrie Marson was the first to say that, looking back on his time, his doubts about the market for research magnets were unfounded and, in fact, the medical market sort of fluctuated and while it became a political passion and so forth, the research market went on very steadily and still does. But, this just puts us on a much higher curve as I was showing you of our growth. It got a very steep jump when NMR came along. There was a little bit of skulduggery going on in that on our part. I remember particularly, I think it was the GE [General Electric] man, coming and seeing it in the old factory down at Osney Mead...

RR GE is the American company?

MW Yes, and saying, 'Well, I've enjoyed today and talking to you, but there's not really much point because you can't make these things, you haven't got a big enough space.' And we said, you know, 'Well, come back in a week or two and you'll see a difference.' Between which time, John Woodgate drew out some marvellous drawings of a building, and he dispatched me up to London to buy the site next door. It was the site you looked out on from John Woodgate's office and you could look out at the foxes and the rabbits and the brambles. It belonged to Rank Hovis McDougall and I went up and I was told to make an offer they couldn't refuse, which I did, and they didn't refuse it, and their man came back and we said, 'That's our site. This is the building going up on it. Where's your order?' He'd got a sense of humour and he said, 'Fine, that's what I like. You contract for a date and a price and I'll trust you.' And we threw this building up in no time flat and, I think, the orders - John Woodgate could correct me on this - came in so rapidly that I'm not sure that we ever made magnets. Perhaps we did, but because it came out too small so quickly, we had to move up to the present factory in Eynsham. As I say, the pull of the market was so extraordinary with all these companies coming in and for a while, I don't know quite how long but I should think about three years perhaps, we were the sole manufacturer for every magnet that was made. There were about sixteen or seventeen separate companies. Thereafter, our share of the market went down. This is typical. Oxford Instruments comes in at the beginning with the sort of people that can translate a new discovery or development into equipment and commercialise on it very quickly, and we had one hundred per cent of the market for a bit, after which there's only one way it can go and it goes down.

RR The investment that you needed for that, I imagine, was the cause of your flotation?

MW Yes, indeed it was. Because we had to buy a piece of land and we had to build a factory and equip it.

RR So the capital required for that was...

MW By then, there were other people involved who appreciated what risk was, more than I did perhaps. I always thought it was going to work and I wasn't so aware of risk, but it was felt widely throughout the company that it would be wise to have a share of the risk with the public and so in 1982 we decided finally to go public and in 1983 we went public quite specifically to raise the order of £11 million, I think it was. We had actually bought the site, but to build and equip the factory cost a lot of money. You buy a site when it comes on the market, you can't wait.

RR Just to give a scale of this factory, I think I'm right in saying that they made one of these imaging magnets every working day of the year?

MW It's a little bit more now.

RR It's more now, is it? I mean, that gives an idea of the scale of the factory. It's huge.

MW You say these are heavy when you lift them up, but I think we used something between one and a half and two tons of superconductor a day in the factory.

RR One and a half to two tons a day? So that I think expresses the scale of the operation.

MW I say that, but I think it's actually gone down a bit because as the performance of the material goes up and it's designed better, the superconducting material is one of the most expensive components of these things, and we spend a lot of time trying to use less of it.

RR The flotation went well, didn't it?

MW Yes, it did. It was quite an exciting time. We learnt a lot. We really didn't know too much about the City at that time. I mean, obviously you have a lot of professional help and it went quite well. It was over-subscribed in the end by a factor of three or four, I think. We weren't asking for a great deal of money by City terms, by our terms it was a lot. The only substantial argument I remember having with our advisers is what we wanted to put in the prospectus. It's a funny thing, but we didn't know how to write the prospectus and the professional people said, 'Look, we'll get one of our junior people to write it and then you can tart it up as you like, but we'll just get the format down.' And he wrote a very competent overall thing, but it was really pretty dry. I'm not criticising, but it was a bit boring to read and we wanted something that would catch people's imagination, so Audrey and I were sent off to smarten this up. I was going to a conference in Grenoble, I think, and Audrey stayed in the hotel and re-wrote the whole brochure. There were a lot of figures, but she got the framework all written. There was a particular bit of the brochure I was very keen to put in, saying that we intended to go on spending a great deal on R. and D., which you've got to in a company like ours, and I produced a sentence saying that sometimes our costs on R. and D. would take preference over dividends. The merchant bank who was helping us was very upset about this. This is actually an understatement. They were absolutely distraught and said, 'You simply cannot do that.' And as you can imagine with most things to do with the flotation, I was totally ignorant and gave in to everything they said, but I would not give way on this one. What they said is that you cannot say that, because the City people will ask for dividends if they're going to invest and I said, 'Look, there are lots of people here who would like to invest in a sort of 'window on science' if you like, apart from an investment. There may be some private people who are particularly after dividends and indeed the big investment houses are too, but long-term capital growth and a 'window on science' are also important factors. I think we've got to put this in because we're going to do this anyway, so we've got to be honest and say what we are going to do,' and in the end they let it through. There's a phrase, and I could show it to you in our prospectus, where we put this in. In fact, it's in here. Can I read it? Because we got a lot of very bad press in the City over this.

RR I remember a rather amusing remark about you.

MW Yes. Well, this is the one I'm going to read to you now. There's one I'm not going to read to you also. This one was in the 'Mail on Sunday' on the 11th September, 1983 - this is not the quote - 'One major dilemma that is a symptom that is typical of small companies involved in superconductivity was how to convince potential investors that we need to continue spending a great deal on development without making them feel that we were not committed to making profits.' Reporters for the financial world were not keen on what they called 'my senior common room air' - I don't think I'd ever been in a common room at that time - and with strong overtones of criticism, I was referred to as 'a boffin who drives a seven-year-old Volvo Estate and wears sandals.' That sort of quote came time and again in the press. The next one is a very upsetting comment, which I'm not going to repeat, but we said at the end. 'To meet our objectives in the longer term, a substantial investment in product development is intended and necessary, and may sometimes take priority over demands of short-term profitability. The Board has confidence that the group management and staff are well equipped to generate profitable growth from these opportunities.' So we sort of grafted in some of the objectives that the merchant bank said we had to...

RR But, in the end it didn't put the investors off, did it?

MW Not in the least, no.

RR Now, when was the company in Carteret bought? Was that before the flotation or afterwards?

MW Afterwards, the main market was for MRI and the quickest people on the uptake with the money to buy these things came from America, as you can imagine. And we were very soon told that Americans will only buy this sort of advanced expensive equipment if it was American made and had an American voice on the reception telephone and so on and so we bought, in conjunction with British Oxygen, a plant in New Jersey just up the road from the Bell Telephone Laboratory in Murrayhill. This was actually in Carteret. We bought this company which had all the cryogenic facilities of helium and nitrogen and so on laid on, where we intended to manufacture magnets and did indeed do so. We transferred the technology and we set this up. It's a history which was later repeated in Japan, that we found that we simply could not get the costs of manufacture in America down to what we could them down to here, and after the reliability of the magnets we were making was proven, our customers in America said, 'We don't care a damn where it comes from as long as its cheap, it works and its delivered on time,' and all the standard things like that. So we decided to stop manufacture in America. However, at the time we bought that company, it had a very small group of people in one corner of one of the buildings making superconducting wire. They'd been offered contracts for doing this and they'd taken them on. They were very shrewd people indeed, in fact, and they grew and grew while we were there and when we decided to stop making magnets, they said, 'That's fine. We'll take over the whole place. We're making profits. Is that all right?' And that has now become, I think, the biggest superconducting manufacturer in the world, of wire.

RR And they make all the special materials that you need?

MW Yes, all the special materials that we need. We don't buy all our material from them and they sell to some other people too, but it's made a tremendous difference to us. If you're making these magnets and it's come up in the conversation several times, the problems you have with materials. You build a magnet and let's say it doesn't work. Why doesn't it work? And there are ten different reasons for which materials is a very common one, but not the only one by any means. You need a very good trusting relationship with your materials suppliers because sometimes when you warm it up and unwind it, you cannot see the problem. But if you've eliminated everything else, then you say well, it must be the materials, and having your own friends making it in very close collaboration made an enormous difference to us. Nonetheless, it's become such a sophisticated business that there are materials that we need from time to time that they don't make, so we do buy from other people and they offer their material to other people, but it's been a great help, that company. A very, very big and important operation.

RR In the meantime, the high resolution magnets were getting to higher and higher magnetic fields and you made a 600 megahertz magnet which became a kind of standard magnet required by all biochemists. You must have made quite a lot of those, I suppose?

MW Yes. The 600 was rather a special magnet because we actually had so much trouble with the 500 megahertz magnet that we decided before we went to the 600 that we would start a special development group, independent of the production system. It's a difficult problem, this. It's the normal policy of Oxford Instruments, or it was for the first twenty-five years or so, that the development was done by production people in parallel. They're very close to the market and they had all the technology and they could develop it and it worked very well in many cases and, frankly, a lot of it was done for somebody who said, 'If it works, I'll buy it.' So that when you sell it, it's then no longer a development project, it's sales, but it worked for a time. But, there came a time, and the 500 megahertz was the turning point in this, when the problems in the production of the 470 or the 450 was such that we didn't put enough development work into the 500 and it was very late in coming. And by the time we set off on the road to doing a 600, we said that we would have a dedicated crew doing it, and it worked so well that we have now quite a substantial development group every time we make the next one before we offer it for sale.

RR Then, in the meantime the magnetic resonance imaging magnets were being made and the scale of the business was becoming obvious. General Electric were making their own imaging magnets?

MW This is a separate business of course. When the imaging business grew up, that was sufficiently different from NMR so that then we had the three parts. There was the original Oxford Instruments making the one-off business, the NMR spectroscopy magnets and then the imaging magnets. Separate groups altogether.

RR But, the competition was growing for the imaging magnets and Siemens were making their own magnets and the Japanese were making their own?

MW Yes. Siemens made them under license from us. Yes, we made them for everybody for a while. Now, some companies, for reasons of security of their technology and their new products, liked to make them in-house...

RR They didn't want to be too dependent on a single company in Oxford?

MW No, and there were at least three or four Japanese companies that were taking magnets from us and they didn't feel comfortable with the fact that we were making magnets for their competitors. Also, the big companies took over the smaller companies. Actually, the number of customers we had went down quite steadily from I should think '84-'85 for the rest of that decade. Siemens was a very good close customer with whom we worked very well always. I think it was partly personal reasons, because actually the people involved got on very well, which is always a great help in business. They didn't really want to make them themselves, but said that they didn't want to be dependent on an overseas small company. We still had a pretty bad reputation for industrial production and so they said that they would be happy to buy from us if they could manufacture a substantial percentage, often half, of their total requirements themselves using our technology and our designs under license.

That went on for a long time, but then they did so well in the marketplace that they found that they were unable to cope with their side of the contract. They couldn't make half of them, and they came up with the suggestion that they close down their manufacturing business in Germany, we increased ours and made all their magnets. But if they were going to do that, they wanted a share in the business, so we then sold half the business to them and now that part of Oxford Instruments is a joint venture with Siemens. We doubled the production here and it's a huge factory. It's a great success. It's become, in its management, its technology and its manufacturing systems a sort of model factory which the Germans send people over to, the DTI bring people down to and so on. We've got all the modern systems of 'just in time' and very special sub-contractor businesses and all the national and international standards for quality and so on.

RR And they have made a huge number of these magnets all over the world, haven't they?

MW Yes, I think we're of the order of well over ten thousand. I think I'm right if I say that thirty thousand people per day have scans done on them in our magnets.

RR That must give you a rather satisfying feeling?

MW Yes, it's a nice thing to have made, and it's the same with NMR. I think NMR actually, if you think of the effect it's had on the development of drugs, it's probably had a much wider effect than MRI, if the truth be known, because there's hardly anything in the pharmacy shop that hasn't seen the shadow of an NMR magnet somewhere or other in the development of it and that applies to everybody, not just to the thirty thousand people a day who go into our imaging magnets.

RR Well, we've reached the stage now where the magnetic resonance imaging magnets are being manufactured on a very large scale and the company is poised for yet further development and I think we have to come to an end with this discussion and we'll continue the story a little later.

MW Thank you.