HOUSE OF LORDS

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The Select Committee on Science and Technology

Inquiry on

NUCLEAR FUSION

Evidence Session No. 1 *Heard in Public* *Questions 1 - 13*

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10.40 am

Witnesses: Professor Steven Cowley, Dr Sharon Ellis and Dr David Kingham

USE OF THE TRANSCRIPT

This is a corrected transcript of evidence taken in public and webcast on www.parliamentlive.tv.

Members present

Earl of Selborne (Chairman)
Lord Cameron of Dillington
Lord Fox
Lord Hennessy of Nympsfield
Lord Hunt of Chesterton
Lord Kakkar
Lord Maxton
Duke of Montrose
Baroness Morgan of Huyton
Baroness Neville-Jones
Lord Peston
Viscount Ridley
Lord Vallance of Tummel

Examination of Witnesses

Professor Steven Cowley, FRS, FREng, Chief Executive Officer, UK Atomic Energy Authority, Professor of Physics at Imperial College London and Head of the EURATOM/Culham Centre for Fusion Energy (CCFE) Fusion Association, **Dr Sharon Ellis**, Deputy Director, Research Councils Unit, Department for Business, Innovation and Skills, and **Dr David Kingham**, Chief Executive Officer, Tokamak Energy

Q1 The Chairman: Welcome. Good morning, ladies and gentleman. We are most grateful to you for joining us at what has been relatively short notice. We felt it would be helpful to have a one-off evidence session for the Committee to understand better the present situation between nuclear fusion research and development, the state of play, and indeed publicly or privately funded research. It is particularly helpful that we have your expertise, representing as you do all these aspects. As we go through the discussions, it is difficult to predict but I am sure we will want to discuss with you the present road map for the research and development programmes, commercial potential and practical implementations, costs, operating and management of UK research facilities, international context and much else. First, I invite each of you to introduce yourselves for the record. We are being broadcast. If any or all of you would like to make an initial statement, please do so. Professor Cowley, would you like to start?

Professor Steven Cowley: I am Professor Steven Cowley. I am chief executive of the Atomic Energy Authority and a professor of physics at Imperial College.

The Chairman: Would you like to make a statement at this stage?

Professor Steven Cowley: I would like to make four points in this hearing. We run the world's premier fusion lab. It is supported more than two-thirds by the European Union, which gives us an unparalleled capability in this area. Secondly, there are many problems in getting to fusion electricity and we have laid out a road map of those problems. It is not just about getting fusion; it is about getting electricity. I am confident that we can do that. Thirdly we have a co-ordinated innovative programme with the US lab at Princeton on spherical tokamaks, one of the most exciting things happening in the field at this point. That co-ordinated programme has designed two new machines that are in the last stages of assembly. Those two machines will yield the critical data necessary before we understand whether this approach yields a viable technology. Finally: the UK's fusion programme is advised by a number of very expert and distinguished committees. Those committees help us to set priorities. They help us to drive innovation and they provide very vigorous review. Those are the four points that I would like to make.

Dr Sharon Ellis: I am Sharon Ellis. I am the deputy director at the Department for Business, Innovation and Skills responsible for sponsorship of the research councils and the UK Atomic Energy Authority. I have nothing further to add to what Steve outlined.

Dr David Kingham: I am David Kingham, chief executive of Tokamak Energy Ltd. We are a private company that aims to accelerate the development of fusion energy. We think that the science of tokamaks, particularly compact spherical tokamaks, is particularly exciting with great progress being made. The development of these compact spherical tokamaks combined with high-temperature superconducting magnets may deliver a much faster route to commercial fusion power. Our approach is basically to treat fusion energy development as a series of engineering challenges.

Q2 The Chairman: That is helpful. Thank you also for circulating your evidence to the Nurse review, which was also very helpful to us. I think we have all seen a copy of that. Let me ask a question about how much money we spend on nuclear fusion research. We have a briefing paper, but it would be helpful if you told us the total cost to the public taxpayer of nuclear fusion research. Indeed, how much do we add to that from other sources, whether European or private?

Dr Sharon Ellis: To start, most of the public funding from government into nuclear fusion research is funded through the EPSRC—the Engineering and Physical Sciences Research Council. It is investing £171 million for the six years up to 2016, and £163 million of that goes directly to Culham, Steve's organisation, which funds research as well as our contribution to the Joint European Torus machine. That investment has levered over £300 million of European investment. EPSRC also invests £3.7 million in a centre for doctoral training specifically on nuclear fusion. That is based at the University of York and over the next five years will generate, we think, around 77 PhDs looking particularly at nuclear fusion. To put that into a bit of context, based on 2013-14 data, which are the last validated data we have, of the total Research Councils spend of £2.8 billion the spend on nuclear fusion represents 0.9%. In a bit more context, the total Research Councils spend in 2013-14 on energy-related research was £190 million, and fusion research represents 14% of that total amount. That is what we are currently spending. I briefly mentioned how much that leverages from the European Commission. I do not know whether Steve wants to add anything to that.

Professor Steven Cowley: I can tell you the current budget of the Culham Centre for Fusion Energy. In total it is just under £100 million a year. This last year, we got £27 million from EPSRC. That includes about £8 million, which is the host contribution for JET. Also £5 million of the EPSRC budget is capital for the spherical tokamak upgrade. The rest funds science and technology programmes. The UK money levers £58 million of direct support from the EU. Including the JET operations budget of over £50 million, research funding that matches the EPSRC funding, and contracts for R&D for ITER—the construction of the large international experiment in southern France. That is our budget. Would you like me to give you some figures on productivity?

The Chairman: That would be very helpful, thank you.

Professor Steven Cowley: In 2012-13, where the data from other labs are available, we produced 446 journal papers that were all published. That compares with the Max Planck Institute for Plasma Physics, the premier German programme that has 4.7 times our budget and produced 696 papers. Thus we had over three times the number of papers per unit of investment. We also received more matching funding from the European Union for the EPSRC money than any of our competitors. There is also a comparison with the US programme at Princeton, which operates the other major spherical tokamak device. We have a machine called MAST and Princeton has a machine called NSTX, both of which are being upgraded and are of comparable size. The NSTX budget at Princeton is $38 million a year. The budget for MAST is £4.5 million. MAST produced 178 papers since 2005 and they have produced 212. We are upgrading MAST—to a £45 million machine. It should come into operation around the beginning of 2017. Commissioning starts in late 2016. The budget for the upgrade of the US machine is $97 million.

The Chairman: Dr Kingham, going back to the funding streams, in your papers you referred to third-party funding that you have attracted. Would you like to tell us about that?

Dr David Kingham: On tokamak energy, we are spending about £3 million a year on fusion R&D at the moment. Some of that is going into conceptual development for longer-term fusion power devices and some into building two small tokamaks that we currently have. The majority of that funding has come from private investors.

Q3 The Chairman: All publicly funded research has to be subjected to a degree of review and assessment of cost-effectiveness. How is this done in the case of nuclear fusion, and what has been the outcome?

Dr Sharon Ellis: The EPSRC is currently conducting a review of its funding and outcomes for nuclear fusion. Professor Peter Littlewood, who is the director of Argonne National Laboratory in the USA and an expert in this field, is chairing that review. It will include consideration not only of fusion research but the relations with fission research. We expect to have the outcome of that review towards the end of the year.

The Chairman: When was the previous exercise conducted, presumably as part of an iterative process?

Dr Sharon Ellis: Before spending reviews, research councils generally review the effectiveness of their investments, and as we are coming up to the spending review this autumn this will be very useful input into our consideration of the proportion of funding that should be spent on fusion research.

Lord Kakkar: Professor Cowley, you spoke about the papers and so on that you have published as a result of this investment. How much intellectual property is being protected? Are you in a position to protect anything, and what is your approach to sharing that for future commercialisation?

Professor Steven Cowley: Everything that we do is essentially part-European. We are an international lab. Two-thirds of our funding comes from Europe. The intellectual property of anything that is funded by the Europeans is owned throughout Europe. That is the

EURATOM rule. We do not own that intellectual property and thus almost everything that we do is open. At this stage in nuclear fusion, the pace of discovery is going to be greater if we tell everybody what we are doing. Later, intellectual property will be developed, but not at this point.

Lord Maxton: I think it was Dr Ellis who said that you were measured by the effectiveness of your spending. Effectiveness can be measured in two ways: first, against whether or not what you are doing is cost-effective; secondly, against the outcome of what you are doing. Which of those are you being reviewed against?

Dr Sharon Ellis: Probably both elements. As part of the review there is consideration of whether the programme is on track in terms of the investment that has been made. The review will come forward with that consideration at the end of the year. Equally, there are additional, spin-off, benefits and outcomes that are being derived from our investment in nuclear research, such as becoming world leaders in robotics and using robotics to handle difficult environments. Emerging technologies have spun off from the investment in nuclear fusion which we consider to be an additional benefit. As well as robotics, there are advancements in new materials. These are things that you need to have in place to ensure that nuclear fusion can achieve its goals, so we are counting spin-off benefits as well as whether the money is contributing to delivering the outcome in the timely manner that we expect.

Professor Steven Cowley: I should perhaps have expanded a little further on this point. We are greatly involved with industry now, and we are involved in three different ways. Because of the building of ITER, the UK has had over £300 million-worth of contracts to supply high technology to ITER. We have an industry office that partners with UK industry and helps it in the bidding process. We are a subcontractor on over 40% of the contracts that have been won by the UK, and in this, of course, we are not supported by direct European money. IP is generated by these contracts, but it is generated for the UK company not UKAEA. Two of the most important contracts that we have won in the last eight months are with AMEC and Assystem UK, totalling €120 million, to supply the robotics equipment for parts of ITER. We provide the specialist knowledge and they provide the general engineering capability. Together we went out and won these contracts, and I hope that by the time we finish ITER we will have won over £1 billion of contracts on that device. These are a superb opportunity for UK industry; it is high-tech stuff, it upskills the industry, et cetera. This is the first way we help industry.

The second way we interact with industry is that we have various “businesses” within the UKAEA supplying things such as diamond window mountings.

The third way is that we use little engineering companies in the UK to provide parts for our experiments and for building our experiments. The MAST upgrade has had between £11 million and £12 million-worth of contracts with UK companies, including Tesla, which makes coils. They have made a superb internal coil for our spherical tokamak with a cyanate-ester impregnation. That is state of the art stuff. We sent people to work on the factory floor with them to develop this, because it was a new technique for them and us. Now they will be able to sell that technique. That is really how we work with industry.

Lord Kakkar: Just to be clear, those areas are outside, let us say, the core. We heard the point about developing new materials, advancing robotics and so on: that if there is intellectual property there that could be protected, it is protected and then clearly commercialised, and then benefit returns to your research institution and so on.

Professor Steven Cowley: If we see an area where a technology is developing for which we can see IP appearing in the future, we have to make a strategic decision as to whether we take European money for it or not. If we take European money, it is completely open and we cannot capture the IP for the UK. We have made some strategic moves to protect some property, particularly in the area of nuclear codes.

Lord Hennessy of Nympsfield: What you have told us is impressive, but is not the whole fusion question unusual in terms of cost-effectiveness, because if we get there it is the most lustrous, glittering prize on a global scale that an innumerate like me can contemplate? I do not want to be unkind, but the cost-effectiveness criteria that you have been talking about reek of the Treasury. You are down in the weeds. If you get there, it would justify everything from Arthur Eddington in 1919 and all the false hopes, the back alleys, the dead ends that you have gone through. If you pull it off, it will trump everything else, so it is an entirely unusual question in terms of cost-effectiveness, is it not? Or is that naive?

Professor Steven Cowley: Around the world a huge amount is being spent on nuclear fusion research, and we have to benefit from all the innovations that the Chinese are doing, the Americans are doing et cetera. The cost-effectiveness of having an international lab such as ours is dependent on being able to pull those things together. We are entirely driven by trying to get fusion as fast as possible, but we realise that we cannot solve all those problems on our own.

Q4 Baroness Neville-Jones: I declare an interest as a member of the Engineering and Physical Sciences Research Council. I am very interested in the debate that has already started. It seems to me that we have heard a great deal about the side benefits that are to be derived from having Culham in our midst, but I suppose my question is this. Professor Cowley, you have described it as a premier fusion platform with unparalleled capability, but what would you describe as the long-term benefit to the UK in spending quite a lot of money—quite sizeable sums were quoted at the beginning—on fusion research? What are we, the UK, going to get out of it?

Professor Steven Cowley: We run the only machine in the world that can do fusion: JET. Out of that we get the capability to run a real fusion device. When the fusion economy comes—

Baroness Neville-Jones: But we do not own the IP to that, do we? As you said, it is an international project.

Professor Steven Cowley: But we own the know-how, and in this business know-how is probably more important than IP. The point is that when the fusion economy comes it will be an enormous economy, and we will be in a position to exploit that know-how, which is exactly what we are doing with the ITER experiment. Doing contracts for ITER is an example of how you will make money out of fusion. You will not make money out of the science of fusion; you will make money out of supplying the parts to engineer the fusion devices in the future. We are doing that for major experiments at the moment, which gives our industry the capability in the future to make money from this product.

Baroness Neville-Jones: And the timetable for developing it and moving forward?

Professor Steven Cowley: There is a series of technological hurdles that we have to get over, so we have laid out a road map to get to fusion electricity in the 2040s. The key step at the moment is to "burn" a plasma. This is the defining scientific moment of fusion. At this point, JET has made some fusion but the fusion does not sustain the plasma. ITER will get to the point where the fusion is sustaining the plasma—where you are not putting any energy in but it is continuing to make fusion energy—this is called "burning". That will be the equivalent of the moment at the University of Chicago in 1943 when they pulled the control rods out of the first fission reactor and it went critical. That moment has not come yet, but it is the consensus of a large number of international scientists that it will come with ITER. I believe that that moment will come in the early 2030s and we will accelerate to the development of the first electricity in the 2040s. That is the plan from Europe, and it includes developing the materials and the blankets, which are where we breed tritium, developing the exhaust system and the balance of plant, which is how you take neutrons and turn them into electricity. This has all been laid out in a detailed engineering document. Can we do it faster? I hope that innovation will drive it faster, but we do not have the evidence for that yet.

Baroness Neville-Jones: I think that Dr Kingham wanted to come in on that point.

Dr David Kingham: I want to address Baroness Neville-Jones' point. I think that things can be done faster through more diversity of approach. From Tokamak Energy's perspective, the UK is a great place to carry out fusion energy development because we can benefit from two clusters of world-leading activity: the fusion research at Culham and the high-field, superconducting magnet expertise built up by Oxford Instruments, Siemens Magnet Technology and Rutherford Appleton Laboratory, which is part of STFC. We are in the right place, and I think at the right time, to make rapid progress.

Baroness Neville-Jones: Perhaps someone else might like to pursue the point about more diversity.

The Chairman: We will come to that in Lord Ridley's question. Would you like to follow up, Lord Ridley?

Q5 Viscount Ridley: My question follows on very nicely from that. I want to explore the area of private funding for fusion R&D and how that will fit alongside public funding. My first question is therefore to Professor Cowley. Do you welcome the development of privately funded work here? Do you see it as a competitor or as a complement? Is it necessary, perhaps, to combat what has been described in some sectors as a closed club consensus bias, which has developed inevitably over decades of pursuing the same project with some cost problem? Do we need, as it were, a red team to challenge some of the ideas behind the conventional way of doing fusion?

Professor Steven Cowley: I am very excited about the developments in spherical tokamaks. I have a very long answer. Let us start with private investment. Private investment in fusion is not new. Hundreds of millions of private money has been spent on fusion. The first project was a high-field compact tokamak by a company called INESCO in the US between 1978 and 1984. Their idea is very similar to some of the things that we are pursuing with spherical tokamaks—trying to make it smaller, cheaper and faster. It soaked up more than £20 million of investors' money and nothing was derived from that programme. In the end, it was not successful. We looked back on what they proposed and found that it had not been properly reviewed and was not technically credible. At the moment, there is well over £300 million of privately invested money in various "fusion" companies around the world. We monitor these companies, and if there are things that we can learn from them, we will adapt out programme. The problem, I fear, is that there is an incompatibility between realistic timescales and investor expectations. That makes it very difficult for us. That is not to say that we cannot accelerate the development of fusion. I hope that the spherical tokamak programme at Princeton and at Culham will allow us to get to fusion faster. I obviously welcome any results that Tokamak Energy may produce.

Viscount Ridley: I want to put a question to Dr Kingham. You mentioned the need for a diversity of approaches and you have obviously seen an opportunity with spherical tokamaks to try something that might be a bit faster. There is implied criticism in some of the things that you have written of the public programme. Is that what drives you? To address the point that Professor Cowley has just made, in terms of the incompatibility of the timescale, does a private initiative such as yours also need public support?

Dr David Kingham: Starting with the last bit of the question, a private initiative such as ours is best funded primarily by private investors, who will necessarily set different objectives for the business compared to those set for publicly funded research labs. The important point is that we can participate in a cluster of activity on fusion where publically funded laboratories are doing basic research and some underpinning engineering developments. Essentially, we look for a jumping-off point from that base to try things more quickly. Our investors expect us to achieve goals at least every one or two years, which sets quite a rapid timescale. Our approach is to set shortish-term specific engineering challenges, such as building the first tokamak to use exclusively high-temperature, superconducting magnets, and then to be able to demonstrate that, as we were able to at the recent Royal Society summer science exhibition. That is an engineering challenge that we believe will contribute substantially to the future development of fusion energy, but it is on a relatively small scale with relatively modest budgets. We anticipate that it will enable us to raise substantially more money, primarily from the private sector, for further development. I should say that we have benefited quite a bit from government funding, for example three SMART awards, an EPSRC CASE studentship, knowledge transfer partnerships and R&D tax credits, which are very helpful for encouraging the leverage of private investment into this sort of area. People appreciate the risks, and R&D tax credits help to offset that risk to a certain extent.

The enterprise investment scheme is also very valuable. If I have one specific request it is that the limits for the enterprise investment scheme be increased to allow us to attract more private investment to fusion. We think that that could be very complementary in the long term to the public science investment.

Viscount Ridley: Are there other things that you are doing, such as the high-temperature, superconductivity tape, that you think would not have occurred to the public project and out of frustration with that you have gone out and tried to do it differently? I do not want to sow discord between you, but I am interested in the relationship.

Dr David Kingham: Our approach is different. The material has exceptional promise for future fusion technology, and many people recognise that. Our approach was to try it on a small scale quickly, which is an easy approach for a small business with limited resources in the location that we are in to take. It would be quite difficult for a big laboratory that is used to big devices and justifying big-scale things to government.

The Chairman: In your evidence to the Nurse review, you said that researchers from UK universities have good access to MAST—the mega ampere spherical tokamak—but there seems to be no provision for UK industrial researchers to have access to MAST. Would you elaborate on that?

Dr David Kingham: That was a specific concern of ours: that our scientists and engineers did not feel that they had sufficient access to what were essentially ex-colleagues at MAST. There is a community of people working in fusion research in the UK, and we would like to encourage as much open dialogue as possible. There have been difficulties in that respect in the past. For Tokamak Energy, this access to scientific data from MAST—the spherical tokamak—will become increasingly important as we move towards commercial devices. We are happy to respect intellectual property rights, but we do not feel at the moment that we benefit as much as we could from the publicly funded fusion research that has been going on.

By contrast, we have excellent access to information on the NSTX tokamak in Princeton. There is a certain amount of openness in the UK. In the US there is much more of a culture of openness in its scientific research laboratories. However, I should acknowledge that Professor Cowley has been kind enough to allow our engineers to visit the MAST upgrade later this week, and we will be pleased to reciprocate if CCFE staff wish to visit our engineering centre.

Baroness Neville-Jones: A very brief follow-up. Dr Kingham, is your approach in Tokamak in any way dependent for its progress and development on what Professor Cowley described as about to take place, or on what ITER is doing on a large scale? Do you need that work in order to be able to progress your own?

Dr David Kingham: Yes, there are far too many challenges for a small company to think about solving all of them, or even a substantial proportion of them. Tokamak Energy basically has to build up its credibility year on year and attract more partners from the public sector and universities and research laboratories around the world. They are going to be wary of us to start with. If we start to demonstrate more scientific evidence and engineering feasibility we will become more of an attractive partner, so we want to build up that national and international collaboration. Hopefully, while concentrating on the engineering we can build devices that others will find very interesting to do work on. For example, the University of Tokyo is collaborating with us at the moment because one of the devices we have already built, and the next device we intend to build, is scientifically interesting to them.

Viscount Ridley: Just a quick follow-up on that. I followed the human genome project quite closely. There was a big international project, which was very expensive, and then suddenly there was a private-sector competitor, but he was partly dependent on what was being done in the genome project. Relations between them deteriorated, shall we say. Is that a parallel with what is happening here? That question is for either of you.

Dr David Kingham: I think we are probably in the process of repairing relationships; it was difficult for a while. Partly that is because Tokamak Energy popped out of nowhere, in a sense, and had some very bold ideas initially. It is only this year that we have been able to produce the level of evidence both on the physics of these compact spherical tokamak devices and on the engineering feasibility, so that we have been able to speak more publicly about our plans and put a stronger case to scientists and engineers around the world.

Professor Steven Cowley: I can see where this is going. In presentations to investors, Tokamak Energy claimed that it could get fusion by 2018. We had several people working with Tokamak Energy. That is not just incredible, it boggles the mind—you cannot get fusion by 2018, not with any of these things. Nuclear licensing would take you 10, 15 years at best; a fusion device is a highly nuclear machine, and so on. So claims to investors of being able to get to fusion by 2018 drove us to say, "We need to have you at arm's length". We are very much dependent on our credibility. Back in 1958, Sir John Cockcroft revealed the ZETA results and claimed fusion for the UK, and it did great damage to the credibility of nuclear research in this country. When you tell your investors that you can do fusion by 2018, you cannot tell them that the United Kingdom Atomic Energy Authority agrees with you, because we do not. We do not think that you can get electricity in 10 years and that that is a credible claim. We have to defend our credibility. In this business we are asking for hundreds of millions of pounds of investment, and if we do not go through rigorous scientific review and obey rigorous scientific standards, that will be a problem. That is the first point.

The second point is that for instance high-temperature superconductivity research is being conducted in the European programme: high-temperature superconducting leads have been constructed at Karlsruhe, research is being done at Vienna, we are in contact with the CERN group, and we work with the Brookhaven group. High-temperature superconductivity is not a new thing in our business. I remember the day when Bednorz and Müller came out with their announcement. We got Philip Anderson the expert at Princeton University over to the fusion lab at Princeton and we discussed what it would mean for fusion. It is possibly a very helpful technology, but it is not going to make fusion happen in 10 years. Credibility, and rigorous review by scientific committees, is very important in this business, we cannot afford to be without it.

Let me tell you what I think about spherical tokamaks. This research largely developed in the 1990s and recently, it is the basis of what Tokamak Energy is doing. I am very excited that we may be able to accelerate progress this way. I am very proud of what Culham has done. A lot of the innovation in spherical tokamaks and the development of the concept happened at our laboratory. In 2009 we sat down with the Princeton team and said, "What do we need to do to understand how this would get to fusion scale?". We made some preliminary designs of what a spherical tokamak fusion reactor would look like. But, we concluded that we could not make that extrapolation, because the physics was not certain enough, and we could not be sure how you would even make the extrapolation. So we proposed two new machines—the MAST upgrade, which is almost finished at Culham, and the NSTX upgrade, which is finished at Princeton—each to tackle separate parts of the problem. We have to resolve key issues such as how you exhaust the plasma if you are compact and you have very high exhaust fluxes. Thus we are now focusing on different parts of the problem. Until we have the data from these machines, we do not know how to extrapolate to fusion performance. Well we can do it, and Tokamak Energy has done it in one way (and we might disagree with them) but we do not believe that there is the scientific data or the understanding to have any confidence in predictions. We made a presentation of our plan to EPSRC, the US made its presentation to its committees, and they said, "You're right. That's the next step to take". If you jump over that step, you take an enormous risk. Maybe you want to take that risk, but we did not think it was credible. That is where we stand.

The Chairman: Thank you. That is a helpful exposition.

Q6 Baroness Morgan of Huyton: I am changing tack on to the role of government. Partly as a result of a report produced by this Committee back in 2013, the Government in their *Nuclear Industrial Vision Statement*—a terrible title, but there we are—identified that fusion R&D should be led by the Government. They also argued that we should be making sure that we were cross-fertilising our research across fusion and fission. I have a simple question, really: first, to what extent do you agree with that and, secondly, is it happening?

Professor Steven Cowley: I definitely agree, because it is a useful use of our capabilities. We run a nuclear fusion machine and we are a premier lab in the world. We (UKAEA) do not have that credibility in fission at the moment because we wound down most, but not all, of our fission research. I was on the Beddington review which looked at the UK's fission research capability and suggested that we try to leverage some of the expertise in fusion to give us a window back into part of fission research. There is progress we are growing our fission involvement. The National Nuclear Laboratory and ourselves are building new centres for the testing of nuclear materials and collaborating at Culham. Our centre is associated with the Sir Henry Royce Institute at Manchester and is part of the National Nuclear User Facility. The key question for next-generation fission is resilient materials. Similarly one of the key questions for fusion is: what do you make the walls of a fusion reactor out of? We do not know yet. We have to test a bunch of materials. But you need a very similar facility for both. The new facility is going to test materials for both fission and fusion. Could we do more? No question: we could.

Baroness Morgan of Huyton: Why is that not happening, or why is it happening, I sense, too slowly?

Professor Steven Cowley: I think that in this country we are still putting together how we want to continue in fission research. NIRAB, which is chaired by Dame Sue Ion, is making a very good job of trying to bring everybody together and saying, "What are we going to focus on?". We cannot do what we did in the 1950s—the UKAEA was an enormous organisation at that time—and blanket everything. We have to have priorities and technical reviews to see whether we are really prioritising correctly. Then, in the end, we must understand how we get value out of it.

Q7 Lord Peston: As background I must say that I am totally confused by the evidence that you have given us. I hope you will bear that in mind. Professor Cowley, you said in your opening remarks, "I am confident that a commercially sustainable outcome will occur". How could you possibly say that? What is your evidence? Also as background, let me point out that it is not even obvious that fission stations are commercially viable. You are talking about things that have never been built and are not within a million miles of being built. How can you express any degree of confidence that this is not a total waste of money? Those were your words: "will occur", not "might occur", and you repeated it a bit later.

Professor Steven Cowley: Yes, I gave you a timescale, which I think is useful.

Lord Peston: "Will" could be between now and plus infinity, but you could not possibly have meant that.

Professor Steven Cowley: No. I think we need fusion later in this century. What we have now are transitional decarbonising technologies, which are fission and carbon capture and storage. At some point we will have to move on from current technology because we cannot do infinite amounts of carbon capture and storage or fission. By the end of the century we need some technologies to replace them. We have done some fusion at Culham: 16 megawatts of fusion power on JET. We can make the conditions for fusion. We have to make a step to the scientific demonstration of fusion, but that still is not commercial demonstration of fusion. Whether we can do that in the 2040s or whether it will wait until 2080 is the question.

Lord Peston: Did you say between 2040 and 2080, not 2014 and 2018?

Professor Steven Cowley: 2080.

Lord Peston: And you think you can forecast over that timescale? I do not know anyone else in the forecasting game who would remotely make a remark like that. I speak as someone who used to earn a good living from forecasting. You are talking about cloud-cuckoo-land, are you not? Sorry, Professor Cowley, I am addressing all three of you on this. It seems to me that what you have done is invent a marvellous system where all the scientists working in this area manage an enormous amount of public money worldwide on a self-sustaining system with no likely outcome worth anything, if I may put it to you wearing my economics hat. If someone were to say, "Surely we just shouldn't spend any of this money, because there are plenty of other good projects in science and technology?", I would find it very hard not to say, "Yes, we shouldn't spend any money in this area".

The Chairman: Dr Ellis is trying to come in.

Dr Sharon Ellis: Obviously my responsibility spans the whole science spectrum, from arts and humanities right the way through to chemistry and particle physics. We take a very strategic approach to investment. I certainly do not tell research councils what they should be funding, but we try to keep a broad spectrum of investments along a range of technologies to try to get us to a better future. Steve has outlined the better future in terms of opportunities for nuclear fusion. So without particular evidence, which is why we have EPSRC reviewing our investment in nuclear fusion, at this moment there is no reason for us to stop investing in this technology. We are active in a European programme. It reports its developments. In the light of evidence, that is the point at which we may or may not review investment in this space. As we currently stand, we still see this as a promising technology. We are getting added benefits in terms of the materials research and advancements in robotics. We are getting inward investment into the UK on the back of it. Taking that as a package and following further evidence, that is when we may or may not take a decision on how much we do or do not spend on fusion. So far, we see the balance sheet in the positive.

The Chairman: Did Dr Kingham want to come in on that?

Lord Peston: Let me just finish this. So your concept is the equivalent of a hedge fund: you put lots and lots of things in it and one of them will pay off.

Dr Sharon Ellis: That is the current policy not only on funding tactical research and applied research that leads to defined beneficial outcomes but on funding universities and academics to have ideas such that when you start with an idea, you have no real concept of what the viable outcome might be. We operate a very mixed economy where we allow the academic sector to flourish and to come up with ideas and new opportunities that have proven to be successful in generating positive outcomes for the UK.

Lord Peston: I apologise, Dr Kingham, I stopped you talking.

Dr David Kingham: I was going to say that economists tend to see the importance of developing fusion energy in quite different contexts to scientists. The economists probably need to be listened to more. If we are to achieve fusion power reasonably rapidly, tokamaks are the best way forward, but a greater diversity of approach would give greater certainty of success. The European fusion road map is the most remarkable linear model of innovation. We know that things do not work like that in practice. It could be argued that setting a big, linear goal to fusion energy is the right thing for public bodies to do because it is a definite big goal and will have spin-off benefits, but the linear model of innovation does not work in practice. Other things pop up, particularly over long timescales. There is a specific risk with the European fusion road map that the slow progress of the ITER device in France will cause a major delay to the whole road map.

Q8 Lord Maxton: I am not going to go down quite the same route as Lord Peston but a similar one. First, 2040 is four or five general elections away. We do not know what the political map will be in 2040. That is how democracy works, even allowing for five-year Parliaments remaining. The first thing is that that could change. The second point is that if you went back 40 years and looked at the technology in 1975, and then went forward another 40 years from now, the landscape would change quite dramatically over that period. Right at the beginning, Dr Ellis, I think you said that there was other research into electricity supply. If Governments find another sustainable electricity supply between now and 2040, I am sorry, but your funding will disappear. Why would a Government, if they get their sustainable electricity, continue to fund fusion? It may be the ideal, it may be what we want, but if you can get something that is just as sustainable if not quite as perfect, why bother spending government money on it?

Professor Steven Cowley: That is true, obviously, but we do not have one now.

Lord Maxton: No, but what research is being done?

Dr Sharon Ellis: There are a range of research projects around, and not simply all on new forms of energy. As part of the BIS capital road map in December, we announced—subject to business case—funding for some wind energy projects. Other research councils have projects around carbon capture and storage, and waste handling. So it is not all dedicated to new forms of energy but to the whole energy generation ecosystem. It is about generation, handling waste and trying to generate new forms. We try to keep a mixed economy out there in terms of what research could bring forward into new forms of energy, but currently we do not have that sort of panacea for the next generation of no or low-carbon energy, and we continue to invest.

Lord Maxton: No one would have thought there would be an internet, and there is one now.

Dr Sharon Ellis: I think that vindicates our approach, which is not only investing in big public laboratories. Part of our Research Councils funding goes to the likes of the University of Warwick, Strathclyde, Imperial, Oxford and Lancaster. We try to invest in people who have ideas and see whether those ideas can be brought forward into opportunities. We will probably never invest perfectly from everybody's point of view, but we try to keep a mixed economy and to pick up what we think the best outcomes might be. You are right. I do not have a crystal ball. We will continue to invest in a broad spectrum and see where that leads.

Lord Vallance of Tummel: I would like to come back to another point made by Lord Hennessy. This is potentially the biggest pot of gold of all time. Is there a relationship between the size of investment and the potential speed of delivery? If it was twice as much or an order of magnitude different, would that make a difference to the speed of delivery? Are there any other roadblocks, apart from resources, which if removed could bring forward speed of delivery?

Professor Steven Cowley: Can I just make a remark? If we are not making progress I do not think one should continue to invest in this. We are making progress. There are scientific milestones, temperatures, densities et cetera. Investment is a very interesting thing. The big investor now in fusion is China. They are training 500 new PhDs per year in fusion and they are going to try to get a device more powerful than ITER. I am not quite sure whether they are taking it through to electricity in the 2030s. The trick there is that they are willing to take a much bigger risk. If you have a lot of cash and take a bigger risk, you can make a step much faster. The difficulty is that the evidence base that that machine will perform is not hugely strong and we need ITER to be sure that that machine will perform. The Chinese are going to take that risk. We are providing some robotic solutions for them. That is good because they will do huge amounts of investment and we both will learn from that. There is no doubt that if you spend more money you will go faster.

Viscount Ridley: To follow up on these points and Lord Peston's point, the one thing every layman knows about fusion is that 40 years ago it was 40 years hence and it is still 40 years hence. How do you counter that trope that is out there? You obviously believe between you that we are now in a position to make that 40-year pledge—or 30-year pledge, or whatever it now is—a little more plausible. What gives you that confidence? On Lord Peston's point, if we can be sure or very confident that 30 years from now we will get there, why can we not get there tomorrow?

Dr David Kingham: From the Tokamak Energy perspective, we think it is very important to try. We think we have the basic ingredients that give us a really good shot at trying to make rapid progress. We are relatively modestly funded at the moment. If we can achieve some specific engineering goals over the next two to three years, we will be able to attract more money and build up the evidence that we are on an interesting track. If we make a slight false move and do something slightly wrong but people have seen a decent track record to date, they will help us recover from a false step and we will make further progress. It is that speed of progress that is important.

There was an article written by Dan Clery, who writes for *Science* magazine, that is probably worth quoting. He said, "From the point of view of the public and politicians, not much has happened in fusion since 1997, when JET made its record-setting DT (deuterium-tritium) shots, and not much is likely to happen at ITER for another decade. This lack of eye-catching results makes it hard to keep funders and fans interested—compare fusion with the constant stream of discoveries made in astronomy and particle physics, for example". He wrote that in the *EUROfusion* journal as a thought piece. My comment on that is that although good progress continues to be made in fusion physics, with some great steps forward, the public will only really get excited and therefore the funding will only really flow if there is progress towards fusion energy. To me, that means engineering materials and unveiling new prototypes and technologies that are on the way to fusion energy. It is that energy goal and the engineering feasibility of the steps on the way that are crucial here.

Duke of Montrose: To a layman, your technology seems to be ideal for servicing base load within the whole. Do you see any way in which you could do more than service base load? Is there a variability in your units of production that could match demand? That is the big thing that the energy field should be looking at: to match your base load with variable generation.

Dr David Kingham: The Tokomak Energy concept for the fusion power plant is somewhat different to the mainstream. We have a concept of 100-megawatt-scale modules, whereas the mainstream view is, I think, of gigawatt-scale modules. We think that should be easier to both develop and finance at that scale and should give more controllability when it comes to operation and response to demand.

Q9 Lord Hennessy of Nympsfield: I should perhaps have declared that I am a fellow of the British Academy. I do not think that the British Academy has any link to fusion, but in case it does I declare that. Can I come back to the 40-years-on problem? I wonder whether there is a consensus between Professor Cowley and Dr Kingham about the breakthroughs needed to reach the equivalent of the Chicago Pile going critical in 1943. Is that a question of engineering, materials or the physics—or a blend of all three? What is the sequence that has to happen before we get to the equivalent of the Chicago Pile? If you could tell me each in turn, bearing in mind that there might be an intelligent sixth-former watching this session wondering what the benchmarks are that he or she can look for over his or her lifetime, to the point where we get there and you get on the plane to Stockholm for the Nobel Prizes.

Baroness Morgan of Huyton: To add to that, I am interested in what the real steps are along the way, not the headlines. I think there is the danger in what Dr Kingham described that it is titillating us with the front page of the newspapers but not really scientifically progressing. It would be very useful if we could understand what the real changes are along the way.

Professor Steven Cowley: The point of ITER, which was very much driven by Sir David King, was that we need to show the equivalent of the Chicago Pile. The Chicago Pile was not a commercial fission reactor. A chain reaction happened.

Lord Hennessy of Nympsfield: It was for the bomb, but it led to civil fission.

Professor Steven Cowley: It was the first chain reaction. It was the scientific thing. ITER is designed—and there was international consensus of what size it should be and how it should be configured—to get to the point where you do not have to put any energy in and the plasma burns, produces fusion power and sustains itself at a temperature of about 230 million degrees. Those were the conditions that we got in JET, but they were not self-sustaining conditions, so JET is not enough. ITER is the step to a burning plasma. The plan is that ITER should be constructed by 2020. But I do not believe that it will deliver the first plasma before 2025. It is a huge international programme that has been very worryingly managed, but that machine will produce the moment in fusion in which we can say that it is scientifically possible.

Lord Hennessy of Nympsfield: You sound very confident again. What are the breakthroughs in R&D and provability that you have to get before that happens? Again you have asserted a wonderful moment, but what are the key steps? If this intelligent sixth-former wanted to know, what are the breakthroughs in materials, physics and engineering you need to get that?

Professor Steven Cowley: I am sorry, but ITER is designed. We need no breakthroughs to get it up and running. The technology of it is set and it is contracted out to industry to build. No breakthroughs are needed in the ITER programme. The question is whether it will produce the needed temperature and the burn. We have some confidence in the physics and the extrapolation of the physics, but we have to see—it is an experiment. We do not need a breakthrough to get ITER.

Lord Hennessy of Nympsfield: Do you agree, Dr Kingham?

Dr David Kingham: I basically agree. There are no fundamental show-stoppers. It is a matter of combining what are basically known technologies in the cleverest way as quickly as you can. The components of that are the spherical tokamak configuration, with its inherent compactness and efficient use of a magnetic field, and within that the ability to engineer high-energy superconducting magnets. It has to be those magnets, otherwise you will waste all your energy-cooling conventional superconductors.

There are then challenges about tritium breeding and handling technologies. They know how to handle tritium for JET; they are working on tritium breeding for ITER. Conceptually it has been sorted out, but it has not been implemented, because no one yet has the device that produces more energy than you have to put in. It is the cleverest way of combining available technologies and sorting out the engineering. Some scientific questions remain, but if we demonstrate engineering progress, that will help enormously to tackle the remaining scientific problems.

Professor Steven Cowley: Can I just butt in again? Sorry, I am talking too much. Getting ITER to work is a scientific experiment—it does not require a breakthrough. Getting commercial fusion requires a number of breakthroughs. ITER will not produce electricity. It will produce a fusion burn, and for only a limited amount of time. It does not have to have resilient walls or the engineering systems around it. However, if we get it, we will be over the major hurdle of fusion; the demonstration that you can get a fusion burn would then be shown.

Dr Sharon Ellis: My colleagues have talked very much in technical terms. The diversification of the research that we have been doing has brought in more of the economics and social-science attitudes towards fusion as a source of energy, because we felt it was important to understand things like public attitudes, and to get a better understanding of some of the economics. So we will continue to think more broadly than, "This is a technical exercise". We need to start thinking about what insights we need to understand if this is to become the next source of energy generation. So we have been encouraging other research councils to invest in the field of energy to get better insights in those areas too.

Q10 Lord Hunt of Chesterton: I must declare my interest: I have done some work in this area and I am an adviser to Tokamak Energy. The fundamental support for fusion around the world is because it will be carbon-free. That is why nuclear power, despite the economics, is important: because it is a carbon-free source of power. This is the big motivation, and it is one of the reasons why China is extremely interested: because it is really concerned about the problems of climate change. That is why there is a technical and scientific drive for this that is to do with saving the planet. That is the argument.

I had a smaller question. Professor Cowley, you said that when you had your meeting in Princeton in 2009 there was some significant physics that was not certain. Recent work has been done by Alan Costley, who has talked to people in Culham and all around Europe. There is some movement—I would like to hear your comments on this—that makes us more optimistic about these developments. This is part of the scientific argument for the possibility of modular tokamaks. When the ITER project was started, as I know from discussions with many people who were there, there were considerable controversies as to exactly whether you needed the size; there was a scaling argument. The scaling argument was based on physics from the year 2000, and some of the physics has begun to change, which is one of the arguments for why smaller systems may be viable.

Professor Steven Cowley: We have known for decades that you have to go either to large size or to large magnetic field, and I think that is what Alan Costley's paper says. There have been attempts in the past to go to very high magnetic fields by using copper magnets. ITER is designed to have the maximum magnetic field with the current generation of superconductors. It is designed on things that we can deliver now. I do not think there is any new information that changes our view of what has to be done on spherical tokamaks at this point.

Q11 Lord Cameron of Dillington: I come to this with quite a low level of knowledge, but reading the briefing it seems that on the UK field we are putting most of our eggs into the magnetic confinement fusion as opposed to the inertial confinement fusion. I wonder whether my perception is right, and whether you think this is a correct approach to the overall problem.

Dr Sharon Ellis: I can talk from the perspective of the advice that we are given. I do not get involved in determining the exact science that is funded. That is not a job for government, which is why we have research councils that determine what should be funded. My sense is that while the majority of our funding, say 90%, is dedicated towards magnetic fusion, if I can call it that, rather than inertial confinement, this is what we will want the EPSRC to look at. Not only will we think about where the balance of funding should go—I would see that as part of its consideration—but part of our thinking is that we are world-leading in magnetic confinement, and it makes sense for us to continue to invest in that area to generate the off-shooting benefits that we have had in robotics, remote handling and advanced materials. Therefore, while we are not complacent and the balance of funding could change, I would be advised by the scientists on making those changes as opposed to something government would take a view on in the absence of any new evidence.

The Chairman: Has the RCUK Fusion Advisory Board given a view on this, and are you following it?

Dr Sharon Ellis: I certainly have not received advice from that particular board that this should change. I know that it keeps a range of things continually under review, and in fact its job is to advise EPSRC and the STFC on what energy research they should conduct, as well as graduate training and our participation in international projects, so it has a very wide remit, and it meets twice a year to look closely at the fusion work that is funded, both domestically and internationally. Its job is to bring forward new recommendations, but currently I have not received those recommendations.

Dr David Kingham: From our perspective, magnetic fusion in tokamaks is a far more promising route to fusion energy than inertial fusion. However, we do like the open nature of the UK Inertial Fusion Energy Network, which is supported by EPSRC and managed by Imperial College. I just found a copy of Alan Costley's paper, which was referred to earlier and which I can circulate to the Committee. It is important. It is quite new in its suggestion that lower power and smaller and hence potentially lower-cost pilot plants and power reactors can be built. These are high-gain, lower-power and smaller devices than previously expected.

Q12 Lord Fox: Following on from some of the issues that Lord Kakkar spoke about, I want to talk about the balance between what we own and are funding nationally and what is happening internationally. The impression that I have come away with is that practically everything we are doing is part of the international field of research, and the ownership of that technology, if indeed there is any ownership at this stage, is in the international sphere and up for grabs. What we are developing is the craft and know-how of doing it. Is that impression right and is that the right balance of investment? Should we be a little more parochial in how we focus our investment profile?

Dr David Kingham: From a Tokamak Energy perspective, we are filing patents and collaborating with others, in some cases under confidentiality agreements. However, ownership of intellectual property is clearly important for us.

Professor Steven Cowley: As I have said, we have tried to protect some intellectual property, but at the moment the benefits for UK industry from our programme come from our know-how and us being able to upskill and help UK industry compete in the high-tech market. We do that very deliberately. We enhance that know-how by international collaboration. We gain from that. We then funnel that know-how, as I said, to AMEC, Assystem and a number of other British companies that we are working with at the moment.

Lord Kakkar: If I may pick up on the important point made by Professor Cowley, you mentioned a very large programme of investment in China and how, if I understood it correctly, robotics developed as part of the programmes here are contributing to making that possible. In terms of ensuring that there are appropriate returns for the work being done in the United Kingdom, not for a European collaboration but for a third party outside Europe, is there any formal assessment or regular review to reassure you that that is the case?

Professor Steven Cowley: Our robotics programme is run by Rob Buckingham, who started a rather well-known SME, which makes the laser snake robotic arm. We, Rob, myself and government have had a lot of discussions about how we protect ourselves from the Chinese when they come in with a juggernaut of money and are all over the technologies that we have developed. Our expertise in robotics comes from JET, which we maintain entirely robotically. We developed that technology over a number of years with European funding. The question is whether we collaborate with the Chinese or try to shut them out and keep our IP. Our understanding is that we can slow them down by a few months by not collaborating, or we could collaborate and get the benefits of what they are doing. We took the second route, but I am not sure that I know the right answer to that.

Q13 Baroness Neville-Jones: I shall ask a question about the relationship between UK contributions to funding and the existence of the programme. It is probably a question for Dr Ellis. I am not suggesting that this is the case, but were the UK to reduce its level of spend in this area, would there be effects on our participation in European programmes? What are the key relationships in the funding, and what effect does a variation in UK spend have on the benefits that we get from the European or international programme?

Dr Sharon Ellis: I am not aware that there is a direct one-to-one relationship with regard the ITER programme. The European Commission has chosen to invest in the UK, and in Culham in particular, because we are the best place that does the work.

Baroness Neville-Jones: Would there be a reduction in that were the UK to reduce its level of spend?

Professor Steven Cowley: The treaty on JET is that we provide 12.5% of the running costs. If we take that money away, JET goes, and then we would have to decommission it, which is rather an expensive proposition.

There is a direct relationship between about €50 million a year in European funding and about £8 million or £9 million—

Baroness Neville-Jones: When you say "JET goes", what do you mean?

Professor Steven Cowley: If we do not pay our share of the funding for JET and the contract is terminated, JET is then handed over to the British Government to be decommissioned. We would then not have the €50 million funding for the operation of JET and would have saved ourselves about £8 million a year.

Baroness Neville-Jones: Could there be a private-sector contribution instead?

Professor Steven Cowley: I am not sure how that would work.

Lord Hennessy of Nympsfield: If we left the European Union, we would be out of EURATOM, because that was part of the communities that we signed up to in 1973, so all this would end.

Professor Steven Cowley: I am not sure whether all countries in EURATOM are in the European Union—your guess is as good as mine. Switzerland is in EURATOM.

Lord Hennessy of Nympsfield: If I remember—I am old, but not that old—when the European legislation was passed in the early 1970s we signed up to that. Is that irrelevant?

Baroness Neville-Jones: It is no longer the case.

Lord Hennessy of Nympsfield: Thank you. I did not know that—question answered.

Lord Hunt of Chesterton: Where are we in the questions?

The Chairman: Wherever you wish to be, Lord Hunt.

Lord Hunt of Chesterton: In response to my previous question I was hoping that I would hear something from Dr Ellis about your policies on climate change. I remind colleagues that we have an Act of Parliament—for 2050, Lord Peston—and that we should maintain a substantial programme until that time. This would be consistent thinking with that. I wonder whether, when justifying this fusion programme, you relate it to the UK's climate change policy.

Dr Sharon Ellis: The current policy is on replacing power stations that are coming to the end of their natural life and looking for a more diverse, secure and lower-carbon mix of energy. In that regard, fusion contributes to that goal. I am sorry if I did not mention climate change in that context, but we definitely see investment in fusion as contributing to those overarching goals.

The Chairman: I sense that we are coming to the conclusion of our inquiry, but Lord Peston has a short question.

Lord Peston: I am a bit lost again—as you can tell, I get lost all the time. How can technology that will be available in 40 to 80 years possibly influence climate change? If we have to save the planet in the next 40 years, we are doomed anyway. You cannot use the climate change argument.

Professor Steven Cowley: We have transitional technologies that last only for a time. Once-through fission, which is the way that we do fission now, will last for about 50 to 60 years.

Lord Peston: All I am saying is that if we have not solved the climate change problem earlier than that, we will have lost the battle.

Professor Steven Cowley: We do not solve climate change and then say that it is done. We will have to keep producing carbon-free energy after we cannot use current fission technology.

Lord Peston: You do not have to persuade me that we have to do something about climate change, but I cannot see fusion as being remotely connected to it.

The Chairman: Dr Kingham wants to come in on this.

Dr David Kingham: A couple of years ago, Lockheed Martin published a video indicating a first fusion power plant in 10 years based on a technology that appears rather unproven. It had a very bold plan from perhaps a weak starting point. That is the timescale that people need to think about. In a sense, Tokamak Energy is trying to get to a breakthrough point where a big company could see a 10-year track to producing lots of power plant modules. That may be our Wright brothers' moment—the point at which big companies think that this is interesting.

The Chairman: I will take a last contribution from Lord Maxton.

Lord Maxton: I am sorry, but I am rather confused by what Professor Cowley said. Why does fission have a lifetime of only 50 years?

Professor Steven Cowley: Once-through fission, which is what we are now planning to do, is current-generation fission. You take the fuel rods, put them in the reactor, burn them, take them out and put them in a geological repository. The Government's strategy on nuclear power says that we can do that until 2040 or 2050 and then we will have to transition to another nuclear technology because it produces a lot of waste and uses up the uranium at a great rate.

Viscount Ridley: Not if you use thorium.

Professor Steven Cowley: That is another nuclear technology, but there are issues with thorium too. Fundamentally, our current plan is to use once through fission as a transitional technology. It does not mean that it will solve climate change, because after 2050 we will have to have another solution.

The Chairman: We have come to the conclusion of our inquiry. You have been very patient.

In setting up this one-off inquiry, we hoped that from our position of relative ignorance—certainly speaking for myself—were we to ask a panel such as this one some of these questions, it would help the wider public understand some of the issues. One point that has come through to me loud and clear, and I hope that members of the Committee will agree, is that we should be proud in this country of the standard of research in this area. It is clear to me that we are of an international standard. I also note that in the area of nuclear fission, we lost our research capacity. I hope that we do not fall into that mistake again until we are quite clear as to the route forward if we are not going to depend on nuclear fusion. Again, I respect Professor Cowley's observation that he must at all costs protect and defend its credibility. We absolutely understand where you are coming from. We have only to remember 1958, which he referred to. I thank all three of you for sharing that information with us. It has been a very informative morning and we have learnt a lot. I hope that the wider public can share in this and learn a lot also. Thank you very much.