HOUSE OF COMMONS

Science and Technology Committee

Oral evidence: Quantum technologies, HC 820

Thursday 28 June 2018, Glasgow

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Watch the meeting

Members present: Norman Lamb (Chair); Bill Grant; Stephen Metcalfe; Carol Monaghan.

Questions 135 - 220

Witnesses

I: Professor Erling Riis, Head of the Department of Physics, University of Strathclyde, Dr Sara Diegoli, Programme Manager, QuantIC, and Professor Timothy Spiller, Director, Quantum Communications Hub.

II: Dr Graeme Malcolm, CEO, M^2 Lasers, Professor Martin Dawson, Head of the Fraunhofer Centre for Applied Photonics, Fraunhofer UK Research Ltd, and Dr Richard Walker, CEO, Photon Force.

Written evidence from witnesses:

- University of Strathclyde
- QuantIC
- Quantum Communications Hub
- M^2 Lasers
- Fraunhofer UK Research Ltd

Examination of witnesses

Professor Erling Riis, Head of the Department of Physics, University of Strathclyde, Dr Sara Diegoli, Programme Manager, QuantIC, and Professor Timothy Spiller, Director, Quantum Communications Hub.

Chair: It is very good to see you all. I will start by saying what an enormous pleasure it is for us to visit Glasgow. We have enormously appreciated the hospitality that you have all shown to us and we have had an absolutely fascinating morning and early afternoon. Thank you all very much; it is appreciated.

We have two hours with two panels, one after the other. Can I urge you all to be as succinct as you can in your answers? We have quite a lot to get through. Don't feel you all have to answer everything. If you feel there is something that you really want to add, then add it in, but we have quite a task in keeping to time, so brevity would be really appreciated. I will start by asking each of you to introduce yourself.

Professor Riis: I am Erling Riis. I am Professor of Physics at Strathclyde University. I am the head of the department at the moment. My research work is within the area of quantum metrology and sensing. Part of our work is taking place in conjunction with the EPSRC hub in metrology and sensing run out of Birmingham University.

Dr Diegoli: Good afternoon. I am Sara Diegoli. I am the Programme Manager for QuantIC, the UK hub in quantum enhanced imaging.

Professor Spiller: I am Tim Spiller. I am Professor of Quantum Technologies at the University of York. I am Director of the York Centre for Quantum Technologies and Director of the Quantum Communications Hub, which is one of the four hubs in the current UK quantum sector.

Chair: You have travelled as well to get here.

Professor Spiller: Yes.

Q135 **Chair:** It is great to be here on this glorious day in Glasgow. It is typical, I know, of your weather. I will start by asking each of you to outline the main applications of quantum technologies that your organisations are involved in.

Professor Riis: Strathclyde University is unique in the UK in that we are involved in all four of the quantum technology hubs that were set up four years ago. We have quite a broad portfolio of activity. I am not going to go into the technical details of this but I can say for my own work within the metrology and sensing hub we are primarily looking at timing, timing frequency standards and developing technology for bringing that to a smaller scale so that it is portable and can be applied in real life situations in the field for a number of—

Q136 **Chair:** Give one or two examples of that.

Professor Riis: You can think about better timing for running the train service, better timing for the financial sector where fast trading requires really accurate timestamping. These are the type of applications you can think of for timing. There is generally a need for better timing in navigation. We have an interest in looking at other navigation technologies that are somewhat further away from the market than timing potentially is. Another area that we have a great deal of interest in in my own research area is the sensitive measurement of Earth's magnetic field and small changes to the Earth's magnetic field. That ranges from geomagnetic surveying, basically looking at what is down there under the ground where you can't easily see it, and it has applications also in human and veterinary healthcare, and there are clearly also defence applications.

Dr Diegoli: Our hub is mostly concerned with imaging systems. We develop advanced cameras. Examples of cameras that we have developed are cameras that can see invisible gases, for example for applications in methane detection, leak detection. We have developed cameras for application in LIDAR; you can think of autonomous vehicles and the need to have situational awareness for vehicles and drones and for autonomous vehicles under water. Quite a lot of our work is to do with imaging through obfuscation, and you can think of murky water, fog, smoke, with applications in a range of industries.

We also have quite a strong development work package for systems and devices, all microelectronic-type devices that you would think of for detecting photons, which are really important components, not just for imaging applications but they are underpinning in other areas of the quantum technology programme as well. Our colleagues have developed quantum entangled sources with a range of applications, not just in imaging. That is the range of our imaging-based systems.

You probably saw the demonstration earlier on. We also have sensors that can measure gravity and those are electromagnetic MEMS for volcano monitoring, detecting voids under the ground. Those are all applications that our MEMS systems can address.

Chair: I should say that they were immensely impressive demonstrations and the age of the people who are working on this is quite extraordinary and very inspiring.

Professor Spiller: Quantum communications is all about secure communications technologies, so the hub that I am director of is producing a whole range of secure communications technologies. They touch on every sector you can think of that needs secure communications: healthcare, finance, defence, government, security, business in general, consumers. We are aiming to push quantum technologies further to provide secure communications solutions across the whole suite of sectors.

Q137 **Chair:** That is nice and succinct. Thank you very much. You win the prize

so far. How big an impact could quantum communications have on cybersecurity? Do quantum communications technologies have any other benefits beyond that core point of improving security?

Professor Spiller: It is not just cybersecurity. It is all manner of secure communications that might be supporting infrastructure as well. The bottom line is that the clock is ticking on our current secure communications infrastructure. If you think there is going to be a large quantum computer that exists in the future, the problem already exists now. If your secure data or whatever it is you are trying to transfer—personal data, medical data, defence data—has a long shelf life of its security you should be worried now. Information that is sent encrypted at the moment can be stored and decrypted in the future and if you are worried about that you have a problem now, not just in the future when the encryption—

Q138 **Chair:** There is a real urgency about addressing that.

Professor Spiller: In terms of reviewing and replacing secure communications infrastructure, that needs to happen now, not just a year before we think a quantum computer may exist.

Q139 **Chair:** Can I ask all of you how much work is there to be done still in raising industry awareness of the opportunities that are available to us with these technologies? Is the current challenge simply one of raising awareness or are more working prototypes and specific target markets required to convince industry?

Professor Spiller: In the communications sector I think businesses that will be end users probably think that is a problem for their service providers to deal with. They may be slightly quantum-aware but I am not sure that we need to push quantum secure communications to them because they will just expect secure communications to be provided by their service provider. I think service providers like BT, for example—a partner in our hub—are already well aware of this. They are working strongly with us on it, so I don't think we need to push awareness to the service providers any more.

Q140 **Chair:** Where does awareness need to be raised?

Professor Spiller: Let me tell you how we are going to do it over the next few years. Part of what we are constructing in the hub is to build the UK's first quantum network, fibre-based, around Cambridge and Bristol and connecting the two together. We think the best way to raise awareness is to actually show people that it is working. Rather than give them yet another PowerPoint presentation telling them that this is coming and it is going to be very good for them, we thought it is better to build it and show them it working first hand.

Q141 **Chair:** Presumably you also have to raise awareness of the risks that you talked about of not getting on with this.

Professor Spiller: Indeed. We are briefing the finance industry, who I would say are traditionally quite conservative to new things but nevertheless we are trying to brief finance, health and so on that this needs to be done. In the end I think they will look to whoever is providing their secure services to just implement something that will be a solution, however long into the future.

Q142 **Chair:** Are you both satisfied with that answer or do you have anything to add?

Professor Riis: I think where we are at the moment is we have achieved a great deal in getting awareness in maybe the small and medium-sized enterprises. We have a great connection here in this area with the photonics industry in particular, which is showing willingness to engage with us in looking at those first stages of developing the prototypes and the demonstrators. Where we probably still have to work hard on the engagement is with bigger players, some of the major companies—some of the system integrators, potentially—further up the food chain.

Chair: Which we do not yet have—the system integrators.

Professor Riis: They are the ones that will be convinced once we have a demonstrator and we have something to show them. Quite frankly, many of these guys don't actually care whether it is quantum or not as long as it works, as long it does the measurement or whatever, gives them the answer that they are looking for. If it is quantum, great.

Q143 **Chair:** What should Government be doing to stimulate demand for these technologies? Is there scope for Government promoting demonstrators outside the field of defence to raise awareness and engage in other spheres?

Professor Spiller: From the perspective of the secure networking, it was actually a recommendation from the Government Office for Science Blackett Review that we should do a serious assessment and demonstration, with the National Cyber Security Centre partnering with us, to test it to see how it works with real data loads.

Q144 **Chair:** What progress is being made in implementing that?

Professor Spiller: At the minute we are taking the first steps in doing that, working with NCSC, looking at random number generation, but once the network is fully operational we are going to set up a permanent operation of that and then we can assess how it copes under potential intrusion or whatever.

Q145 **Chair:** We heard in our last evidence session that the national programme has under-supported quantum computing. It has not been a particularly dominant feature. How much focus do you think the next phase of the national programme should place on quantum computing?

Professor Spiller: You say under-supported.

Chair: That was the evidence we have had. It is not our view.

Professor Spiller: One out of four hubs was chosen and I think the honest answer is that the UK chose to make a bet on one of three possibilities in quantum computing. It chose to do small, scalable ion traps that can be bolted together as opposed to condensed matter quantum computing as opposed to optical quantum computing. One of the three was chosen. All three would have gobbled up the whole phase 1 and so none of us would be here, but I think that would have been a mistake. I think in phase 1 the balance was right. Optical quantum computing is now a start-up in California rather than a hub in the UK, so I am not sure that we are going to pick that one up. There is probably a case for whether it is another hub or whether it is an expansion of the existing one on quantum computing to include the solid state expertise that we have in the UK. It depends if there has to be a trade-off between stopping some other things and whether we can afford to keep everything running in parallel.

Dr Diegoli: If I can build up on what Tim was saying, I think one of the strengths that the national programme has had in its first phase has been the variety of applications that we have been exploring through the four hubs. That has also meant that if you look at the timescale for products getting into the market, you have a range of products expected in the next 10 to 15 years but also with some earlier prototypes and earlier technology we can reach markets sooner and help in engaging industry and promoting quantum technology as a technology for today rather than one that we need to think about in the longer timescale. I think it would be a real shame if further investment in the programme undermined the variety and the different timescales that we have seen, with the majority of nearer-to-market products coming from the imaging and sensing sector.

Q146 **Chair:** That diversity has been a real strength of the programme so far?

Dr Diegoli: That would be my argument, yes.

Q147 **Bill Grant:** What role do you see for the existing hubs that we mentioned, the four hubs, in the next phase of the national quantum technologies programme? What do you see as their role and how do you envisage them integrating and interacting with the proposed innovation centres? How do you bring them together?

Dr Diegoli: I will take that question in two parts. On the future of the current quantum technology hubs, I see very much that the hubs have reached the goals that they had set out, which was to demonstrate the applicability of quantum technology to real world application within the timeframe of the first round of funding. Moving forward, I think the model that the hubs have adopted has been very successful in doing so. There have been some components that really have made a difference and some of it was our partnership resource in terms of flexible funding to be responsive to engagement with industry and the direct participation of

our industry partners in allocating and in prioritising the investment of that funding. We also have been well resourced in our business development activity to engage professionally with industry and being able to reach out to our partners.

Moving into phase 2, I think that we would very much want to see all of those characteristics retained in the structure of the hubs but clearly there needs to be a refreshment of the topics. Some of the technology we have been working on has matured and needs to move into new funding mechanisms and new challenges. New emerging strands of research coming from fundamental research need to come into the pipeline of the hub and be accelerated through that mechanism. The mechanism is solid but it needs a refresh of the content of it.

The second part of your question was about the innovation centres and integration with the hubs. I very much see the innovation centres taking a central role in accelerating the technology that is emerging from the hubs—and not just from the hubs but that is emerging in general from UK academia—into those system integrators that at the moment are not engaged in the programme probably as much as we would like them to be. That is about standardising, having system integration, having the ability to test and validate those subsystems until, as Erling was saying, it almost does not matter if they are quantum inside or not; they work and they work better than current subsystems.

Professor Spiller: On phase 2, we have been asked to draw up a revised portfolio that will include significant new areas, for example communications in space, that are not covered at all in our phase 1 activities and entanglements. We have in mind a significantly evolved portfolio in the whole concept for phase 2.

On linking to the innovation centres, I have a little bee in my bonnet about it. I think the spirit of that recommendation in the Blackett Review is that there needs to be significantly more innovation in phase 2. I don't think anyone would argue with that. It needs to be weighed up whether it is done through separate innovation centres or through increasing the innovation that is done in some kind of hub structure. I have two cautionary issues with separate innovation centres. The first one is that I remember when Innovate UK was called the Technology Strategy Board and they focused on the very high technology levels and EPSRC focused on the very low ones and there was a big gap in the middle. I am afraid that if we have innovation centres and hubs that are focused on research and innovation, there is a danger of that gap.

Q148 **Chair:** Are you a lone voice expressing that concern or are there others who have similar—

Professor Spiller: Every time I bring it up everyone agrees that that should not happen, we must not let it happen. I don't know whose responsibility it is to stop it but we had better make sure it does not happen; otherwise we will reset 10 years.

Q149 **Bill Grant:** What would your preventative measure be? I would say it is a real—

Professor Spiller: You have to make sure that the whole space is covered. If you tell academics to focus on research and you tell the industrial folk to focus on the last few steps towards products, people will look at each other and say, "Who is doing the bit in the middle?" There has to be joint responsibility to see that that does not happen.

The other issue with separate things is that you have many interface points where you do tech transfer between a hub or an academic group and an innovation centre and someone has to manage all of those transfer points if there are going to be separate entities. I am not saying it can't be done but I think those two things need to be kept in mind.

Q150 **Chair:** Do you agree with the concerns that Tim raises?

Dr Diegoli: I agree it is something we absolutely need to avoid, but I feel that if the hubs are maintained in the current translational role and they are not moved in their remit towards the science basis, that interface could be made to work between the hubs and the innovation centres.

Q151 **Bill Grant:** What do you think is the role of innovation centres? What should they be doing that hubs may not be doing? Should they be the organisation that reaches out to industry? Whose job would it be, a hub or an innovation centre, to reach out to industry?

Professor Spiller: If I look at what Innovate UK say innovation centres should be doing, most of that list is covered by what the hubs are doing. I would agree that the hubs are not doing enough of the innovation-focused things but we are doing some of them. At the moment it is the hubs' job to do that because we are not research entities. We were told at day one that we should be doing technology development not research, so we are playing in that middle space. I agree with Sara, if we stay there that is fine but the sense we are getting is that we should maybe focus on research in phase 2. Then I fear that it could be a valley of death, or whatever you want to call it, in the mid-technology space, so we just have to watch for that.

Dr Diegoli: I think we are pretty much saying the same thing. It is just a question of seeing in the details how these mechanisms are going to be developed.

Chair: The design of the interaction is critical.

Dr Diegoli: Yes.

Q152 **Bill Grant:** It is a numbers game, four hubs and four innovation centres that work together to a degree, or is that too simple?

Professor Spiller: What I have heard is that innovation centres should be a geographically-focused thing, bringing a lot of stuff together, which

may be appropriate for other areas but in the communications sector, communications is all about stuff being spread out. It is not localised. Our network is going to go across a significant part of the UK, so it would make sense to us to have innovation activities at different points on our network rather than bringing it all together in one place. Putting a geographical focus for communications might not be appropriate anyway; we should spread that out.

Bill Grant: I am not suggesting spreading the butter thinner but maybe spreading the organisation of the innovation centres.

Professor Spiller: Yes.

Q153 **Bill Grant:** The innovation centres should not be hosted by the hubs; they should be separate. Is that what you are saying?

Professor Spiller: I think if they are going to be innovating in a way that is done according to what Innovate UK are seeking, they have already said that it might be hard to do that in a university-led environment, and I can see that. They basically said they should be led by companies. I don't particularly have a problem with that, but then we need to manage the interface between innovation centres and hubs.

Q154 **Bill Grant:** You see a link between universities, innovation centres and industry – there is going to be a connection between all three. They are all key players in there.

Professor Spiller: Yes, and I think that connection needs to be set in a very particular way; otherwise, we will run into problems at the interfaces.

Dr Diegoli: Probably not one size fits all when it comes to innovation centres, but from our perspective we would see an innovation centre to be around critical assets and those could be intellectual assets, facilities, when a particular supply chain or a critical mass of a supply chain is present. That is what we are looking at in our own interaction with industry on their desire for innovation centres.

Q155 **Stephen Metcalfe:** For the sector, this emerging industry, to make the most of the potential it obviously has, we need to develop the supply chain. What is the key to developing a supply chain to support quantum technologies, or how would we develop it?

Professor Spiller: Let me make one comment to kick off. In the comms sector, the technologies, we understand what we need to put those together. I think certainly in phase 2 we have more concern about the supply of detectors and sources and components that will go into those than we have had in the past because of the changing events across the whole world for supply of those things. From our perspective, but this is peculiar to our sector, we want to make sure in phase 2 that we have the ability to get both sources and detectors and the ability to integrate those so that we can build these technologies in a UK-capable way rather than

relying on supply from elsewhere. That is a new perspective that has come in since phase 1 started.

Q156 **Stephen Metcalfe:** Is that going to happen on its own or does that require spin-outs and start-ups?

Professor Spiller: We have built it into our projected hub portfolio for phase 2. Before we had been buying this stuff in; now we think we ought to pay more attention to seeing that it gets built. Some of the new networking stuff we want to do will need rather technical sources that may well only be available currently in university labs and so on. We are having to grow that supply chain from the bottom up.

Q157 **Stephen Metcalfe:** Is there anything we can learn from the US or Canada? Have they done it in the same way as us?

Professor Spiller: In the US a major source of detectors has disappeared, which is one of the reasons why we are now more focused on making sure we have alternative sources for that. I am not sure we can learn much from that. That is a company that was taken over and now what it used to sell is no longer on its list, so we have to buy it from elsewhere.

Professor Riis: I think that we should not always look far away. We have done a pretty decent job in the UK community already in this area of developing the supply chain. We have engaged with our local photonics industry and they have an awareness of the potential for quantum technology and are willing to engage with us in developing some of these early supply chain parts.

Q158 **Chair:** Would you say that both Strathclyde and Glasgow universities—I appreciate you are from only one of those—have been very good at engaging?

Professor Riis: That is what I would like to claim, yes. I think we have done a decent job of this already.

Professor Spiller: Peter Knight told you already that photonics is very strong in the UK but there are many small companies, not three big ones. I think we are well set in that sector particularly.

Dr Diegoli: We feel that the innovation centres will play a major role in consolidating that supply chain and bringing that together.

Q159 **Stephen Metcalfe:** As we move forward to the next phase of the national programme, what governance structure do you think should be in place for that?

Professor Spiller: Is that the question about the recommendation in the Blackett Review for having a board that probably has more teeth than the current strategic advisory board?

Stephen Metcalfe: Yes. Has the structure worked?

Professor Spiller: There is an argument for that because, particularly if you have separate innovation and hub activities, there may well be some issues there that they are managing. Rather than having just a strategic advisory board, a strategic governing board or whatever you want to call it that makes decisions about how the programme works would probably be very useful to resolve those things. In phase 1 it has been advisory. Having more oversight and being able to dictate how the programme evolves in phase 2 would be very useful.

Dr Diegoli: One of the strengths of our national programme has been the fact that it has functioned as a national programme, bringing together academia, Government and industry stakeholders. As the programme grows in phase 2, now we have added the skills hub to the quantum technology hubs, we are looking at possibly investing in innovation centres. There are ISCF projects in this area. I think that co-ordinating and bringing together when we present our capability to industry, when we engage with large corporates, having a single portal or having an overall national approach to some of these topics will be really helpful. We advocate for a national approach to this.

Q160 **Chair:** Are we unique with our national programme or are there other countries that are doing it as well or better than us? You seem to be very positive about the design overall of the national programme. You have one or two concerns about ensuring that phase 2 is well designed, but do you think we are ahead of the game in the design of this programme?

Dr Diegoli: That is my view, yes, and this has been corroborated by the fact that a number of other countries that have now invested in quantum technologies are very much looking at the UK as a model for bringing their national programmes together. That critical mass helps in not spending a lot of research pounds in unco-ordinated ways.

Q161 **Chair:** Do you have any view about the Government's response to the patient capital review and the opportunities there to leverage more private resources into growing companies in this country?

Professor Spiller: I think that is a good thing. I still think the environment for starting new companies in the UK is not perhaps as good as it is in Silicon Valley, California, or in places in Canada. The funding is one thing. We need a bit of a culture change in the UK. A quick anecdote: when I was at a conference in the US with a US colleague when I worked for Hewlett-Packard, he pointed out, "That professor has had three failed start-ups, that one has had two, he has had one failure and one that has worked." A failed start-up in the US or Canada is like a badge of honour; in the UK it is a badge of shame.

Q162 **Chair:** Do you have any failed start-ups, Tim?

Professor Spiller: No.

Chair: You fail to have a badge of honour?

Professor Spiller: Yes, I do. We visited Canada—the UK sent a delegation over there earlier this year—and in Waterloo they had an innovation space where students were taking time off their degrees and just trying to invent something for a few months. This place was full of people trying to invent something. It looked like a health and safety nightmare—I don't know who did the risk assessment—but I have never seen anything like that in the UK. That was bringing in a culture at the student undergraduate level that it is okay to try stuff and if it doesn't work you try again. We need to bring that into the culture. As well as just making money available, I think we have to change the culture a bit as well.

Q163 **Carol Monaghan:** Can I ask about the funding for the national programme and the challenges that might present to the UK's quantum technology sector if that funding is delayed or does not come through at all?

Professor Riis: That would be a bit of a problem. We all have research staff that have the same end date on their contracts. If we do not have a continuation of the funding at that point, I think we stand a really good chance of exporting a lot of our talent across the world and helping all those other countries that have looked at the UK programme with envy. It is very much on my mind to emphasise the importance of having a continuation once we get to the end of phase 1. We have all written down 19 November as the day.

Q164 **Carol Monaghan:** Do you feel that at this point you should be getting assurances for 19 November?

Professor Riis: I think my research staff would love to have that assurance for 19 November.

Q165 **Carol Monaghan:** We have heard some warnings from other evidence against the strict industry-matched funding requirements. How do the Government incentivise industrial investment without potentially jeopardising growth in the sector?

Professor Spiller: Sometimes the Innovate UK rules on matched funding are a bit too rigid. In EPSRC projects where the industry provides matched funding, that can be some sort of in-kind contribution. With Innovate UK projects it always has to be cash that is on the bottom line. I think they could be a bit more flexible about what is deemed to be matched funding and that would be very helpful. The other thing to bear in mind is that we are talking about a new disruptive technology here and if you expect big companies to find substantial matched funding to put into a disruptive technology when they could put that into their existing business instead, it is a difficult choice inside a large company.

Q166 **Carol Monaghan:** There is a risk there?

Professor Spiller: I think there is a risk. Clearly we need industry to buy in; otherwise we are not going to have markets growing in the future and

so on, but asking industry to do too much too soon in disruptive technologies is quite high risk. You then run the risk of things not being totally covered.

Q167 **Carol Monaghan:** Are any of you aware of this industry-matched requirement posing difficulties for academics bidding for funding? I know we have a lot of industry partners represented here this afternoon and that there are strong links here.

Professor Riis: We have just gone through this round of the Industrial Strategy Challenge Fund, which was the pioneer funding associated with that. They were £3 million to £10 million projects with industrial engagement at the 70% level of that or thereabouts, and it was a little bit of a struggle to find the industrial match to that. It was successful in many cases but there were also situations where it just was not possible. That was an example where there probably was a bit too much of a bar to get across, whereas we have had a system in the past with Innovate UK where it was smaller projects–£500,000 to £1 million projects–with matched funding from industry. In some ways it was much easier to get across that lower bar than getting past the £2 million, £3 million one. I think we have probably lost something there that we had in the past. I would advocate looking at reintroducing an element of the smaller projects that have worked really well in establishing the supply chain we were talking about.

Dr Diegoli: I strongly agree with Erling. I think ISCF has been fantastic in raising, in some cases, the ambition of the projects that we have been looking at with our partners, but there is definitely a space going forward to maintain the small projects, especially in a supply chain that is now mostly made up of SMEs.

Q168 **Carol Monaghan:** What are your thoughts about the funding of blue skies quantum technologies research coming from the funding council as opposed to the national programme looking at funding and commercialisation?

Professor Spiller: The funding councils' support in basic quantum research should be maintained or expanded to feed this. There is always a danger of pulling money across from the basic use of its budget. EPSRC, or whatever the relevant council is, still should have a budget for basic science but the hubs in phase 1 were told that is not our territory. We are picking up the stuff that has already come through EPSRC and we are supposed to be taking it through to development and, as far as we can, towards commercialisation. That worked quite well in phase 1. There is still basic research funding and most academic groups involved in the hubs also have basic funding coming from EPSRC. That has worked pretty well in phase 1 so I am not sure that that needs changing.

Q169 **Carol Monaghan:** Is there a danger with that that the funding becomes siloed? You spoke earlier about this problem between the research and the actual product. Is there a difficulty, if the funding is siloed in that

way, that we build up a barrier between the two?

Professor Spiller: No, I think the difficulty is further over. Most of the transfer between basic research and then what the hubs have been doing in phase 1 is carried out in an environment where probably the people doing the work have a foot in both camps, so that is fine. I don't think there has been much of a transfer issue there. The transfer issue can occur where you are effectively handing it over from one kind of entity called a hub to another one called an innovation centre. I think there is more of an issue there than there is down here.

Q170 **Chair:** Tim, are we going to avoid a so-called crypto-apocalypse?

Professor Spiller: I don't like the word. I don't like it for two reasons: one is that I think it is hype and the other is it suggests it has not happened yet. I tried to make the point earlier that you have a problem already. If your data has a 50-year security shelf life and you are communicating it around encrypted now, people will be noting it down and they may well break it in 20 years' time or whatever. The problem exists now whereas the apocalypse thing suggests it is out there on the horizon. If you are really worried about the long-term security of communications—

Q171 **Chair:** While you don't like the term, it is here now?

Professor Spiller: It exists now. We need to be thinking about it now.

Q172 **Chair:** What do we do to avoid it or to limit the risks of it?

Professor Spiller: Please don't get the impression that quantum communications is going to solve everything. People are also pursuing other forms of secure communications based on evolved conventional mathematical cryptography that they think will be immune to attack from a quantum computer. It is going to be very hard to prove immunity because you don't know about algorithms that people have not invented yet, but you can certainly see immunity against the current algorithms that would be used to break conventional public key encryption in the future. At the minute the two best bets we have are improved mathematical cryptography that is immune to attack from a quantum computer and quantum communications that gives this physical aspect of security so you know you have been eavesdropped upon. Those two things together in combination or one solution here, one solution there or whatever, are our best bets at the minute going forward.

Q173 **Chair:** If there is a concern here and now about secure storage of data, what is the solution to that? You say we need to act on it now but what do we need to do?

Professor Spiller: For storage you are always going to rely on physical security and people not transmitting stuff out that they should not. If people don't follow the rules when it comes to secure communications you have a problem anyway, so you need to make sure that people do what they are supposed to. You are going to rely on the physical element

of security for data storage anyway, whether it is encrypted or not. At some point it gets decrypted because people need to read it and look at it. So you have to have physical security.

Q174 **Chair:** It comes down to human beings?

Professor Spiller: There is a strong element of that, which we should not forget.

Q175 **Chair:** The police are struggling to access information encrypted with current methods—there is a WhatsApp issue about terrorists sending messages through that format. Would there be any technical solutions to allow interception of quantum communications by law enforcement? Could standards be developed to enable those?

Professor Spiller: At the minute the answer is yes, because we can't do quantum communications over arbitrarily long distances. The network that we are building in the UK will have what are called trusted nodes where if you wanted to do a lawful intercept, you go along to whoever owns that trusted node, whether it is Openreach or whatever, and you produce your warrant and you intercept. If we could produce long distance, secure quantum communications you do have a problem, and the way you would have to deal with that is to implement trusted nodes anyway. If you really want the ability to lawfully intercept at a certain point, you would have to have guarantees of secure communication between here and here but if you want to intercept you can do it there or there, but you have a promise that no one will be intercepting while it is encrypted between the two, so there are only certain points where the interception can be made. Off the top of my head, something like that sounds to me much better than building in a deliberate back door to crypto. The moment you build a vulnerability into the system that can be unlocked then other people can unlock it too. It is better to do it with physical trusted nodes at certain places where you know you can access data.

Q176 **Chair:** What is the UK quantum network used for currently and what is it working towards?

Professor Spiller: What it is used for currently is just sending around lots of data that has been encrypted and quantum keys down the same fibre. We are basically demonstrating that we have robust, stable, long-term, secure communication services that work. We are proving that point at the minute. We plan to have this work with the National Cyber Security Centre to investigate that over a period, so that would satisfy the one Blackett recommendation. This network was funded by public money so it is not going to be used for profit. We are not going to run a service on it but what we want to do is run a demonstration service and then get user engagement. The network has been put in places where there are significant potential end users—in Cambridge, all around the BT site in Bristol. We want to engage with people and demonstrate it working.

Q177 **Chair:** Will it be able ultimately to certify and accredit devices?

Professor Spiller: Certification of secure comms comes from GCHQ. The way it would have to work is that you have standards in place and you want to make sure that the things satisfy the standards. In the end, because certification of quantum technology, certainly in the communications sector, involves certification of this hardware, the model could well be that the National Physical Laboratory would do the certification measurements under the auspices of GCHQ and NCSC and that would give certification. I think the Government would want NCSC's seal of approval before they start using this technology for actual working services. The route has to be that the National Physical Laboratory does the measurements and NCSC does the overseeing role.

Q178 **Chair:** Thank you for that. We have completed the questions for this panel but before we change the panels, are there any final thoughts any of you want to offer us on the basis of the discussion we have had, or have you said all you want to say?

Professor Spiller: You asked about the crypto-apocalypse. I mentioned post-quantum stuff. I assume that you are aware—somebody has mentioned it and I don't know if it was in the written evidence—that the National Institute for Standards in the US is running a competition to find new quantum- proof algorithms. At the minute people are sitting and waiting because the quantum communications technologies still need to be developed just that bit further and made a bit less clunky, and cheaper and smaller and so on. In the post-quantum crypto arena we are waiting for this competition to give a suite of new mathematical algorithms. I think once we have those two things moved along a bit, we will be well positioned to start implementing that. You should be aware that that competition is ongoing at the minute and I expect the results in a year or so.

Q179 **Chair:** Will it have global application?

Professor Spiller: It will. There are certain nations such as Russia and China that may choose to use their own things, but I think there will be pretty widespread adoption worldwide of these new algorithms once everyone is agreed that they are as good as they can be made.

Professor Riis: One thing we have not touched upon is the training of people who are to fuel this new industry. This is a full range from apprentices who are working on putting things together, engineers, scientists, all the way out to PhD level. It is very important to keep that in mind.

Q180 **Chair:** Does the second phase need to have a component that addresses the need to have an education plan?

Professor Riis: We need to maintain that. It is certainly in the first phase and I think the second phase should have that as well and it probably should be widened to look at a broader spectrum.

Chair: Not just at the top but at the—

Professor Riis: We tend to look at the top. If you ask an academic about training of people they immediately start thinking about PhD students. It is much wider than that. It is all the way to the people who are producing these things ultimately. They need to have various levels of understanding of what it is and that is an important aspect as well.

Chair: Thank you all very much. Thank you, Erling, for hosting us this morning. We appreciated your time and that of your colleagues as well. Please pass on our thanks to them.

Examination of witnesses

Dr Graeme Malcolm, CEO, M2 Lasers, Professor Martin Dawson, Head of the Fraunhofer Centre for Applied Photonics, Fraunhofer UK Research Ltd, and Dr Richard Walker, CEO, Photon Force.

Q181 **Chair:** One of the witnesses has just escaped. He is coming back immediately. While we are waiting for Graeme to arrive, perhaps you two could give us some introductions.

Dr Walker: Thank you very much, Chairman, for the introduction. My name is Richard Walker. I am the co-founder and CEO of Photon Force. We are a small start-up based in Edinburgh and we design and manufacture and export globally time-resolved single-photon quantum image sensors. Those are used by our customers in quite a diverse range of applications, Things like seeing around corners and seeing through scattering media capture the imagination but also there is a lot of work going on in life sciences with bioimaging, where our customers are using our cameras to detect these individual photons, very precisely in time; they are able to do it faster than we have been able to do it in the past.

Professor Dawson: I am Martin Dawson. I have two main responsibilities. I am a professor at the University of Strathclyde in the Institute of Photonics and in that capacity I lead for Strathclyde's work in two of the quantum technology hubs, the QuantIC and the NQIT hubs. Since 2012 I have been the head of the UK's only Fraunhofer research centre, Fraunhofer CAP. We have deliberately targeted from the beginning the UK's national quantum programme as a key area that the Fraunhofer CAP can contribute to and we have built up a substantial portfolio of activity within the Fraunhofer Centre relating to quantum technology.

Dr Malcolm: I am Graeme Malcolm. I am the co-founder and CEO of M Squared Lasers. It is a 100-person photonics and quantum technology company. I think we can say we are the largest integrator of quantum systems in an indigenous UK-based company in that regard. Our laser technology has become very important in the area of cold matter for quantum. We make atoms and ions cold and then provide the light that can address the quantum states there. From there we have integrated to

make some of the early stage demonstrators of the world's most accurate clocks, sensing systems and computational systems for quantum.

Q182 **Chair:** You will have heard what I said to the first panel: try to be succinct if you can, don't feel that all of you have to answer everything. I will start by asking you all to reflect on the national programme so far, whether you feel it has been a success and whether you feel that the second phase is heading in the right direction, provided there is funding for it. Give us your views on the direction of travel as well as your reflections on the programme to date.

Dr Walker: We have engaged in a couple of projects through the first programme and also with the quantum hubs. I think in that regard it is incredibly beneficial that that support has been there for industry to help work with our academic colleagues to take some of these technologies further. There are probably a few specifics and some suggestions we might comment on as we go through for the Government for making that support available; there are details to consider, but it really helps to kick-start the industry.

Professor Dawson: I would echo the comments that were made by the earlier witnesses that the UK programme has really been a flagship for the rest of the world. I think we have chosen the right themes for the hubs and the hub structure has worked very effectively. Innovate's support in particular has allowed industrial organisations to engage with the programme, as have the hub activities. As we heard, the hubs have laid out very exciting plans for a second phase and I think those are just the right things that need to be done. We talked earlier about the need to accelerate the engineering and I think that is a crucial element for the second phase of the programme and I guess we will come back to discuss it further later on in the evidence session.

Q183 **Chair:** You think broadly plans for phase 2 appear to be moving in the right direction?

Professor Dawson: Absolutely, yes.

Dr Malcolm: I take all those comments and the previous comments. I think the thing that has particularly been important and a particular advantage has been the way that the triangle of Government, academia and industry have all operated together, with Government to fund and convene the necessary people to come together in this programme. I think a particular strength is that it has been very inclusive across all of those bodies of the partnership. That level that has included everybody in academia and industry with interests in this area and all the different branches of Government has been pretty unique in any form of technology journey that I have seen. That has led to a lot of the success stories that we had earlier because the first thing that we did was get everybody in rooms together to begin dialogue. The things that we are seeing now for the second phase really build on that. I think there is a global increase in urgency in that as we see other countries starting to

realise what a step change in technology this is going to be. I think phase 2 sets us up well for that. Some of the things we have talked about on innovation centres and how we need to avoid that gap in the next stage of the process are—

Chair: Between the innovation centres and the hubs?

Dr Malcolm: Yes. I think that is a particularly important element because the key missing piece globally is that next stage of innovation to take on the good work so far and get it into some real world applications.

Q184 **Chair:** Graeme, your recent evidence made the case for benchmarking the UK's quantum sector against other nations. What details or metrics would you want that to cover and what use would it be to Government, industry and academia? What is the purpose of it?

Dr Malcolm: The first thing it does is help contextualise the global landscape. We were part of the Canada mission, so we learned a lot about what our global partners and our global competitors are doing there. It helps contextualise things at a global level but it also helps us really understand the way we are starting to move the dial on the impact. We want to contextualise our research inputs but we also want to contextualise our economic output so that we can see the benefits of quantum here. Individual countries have their own processes, their own way of giving support for quantum, some way of always being able to balance the global playing field to understand—Korea has direct Government intervention; the US has military and industrial and government contracting that supplies their chain. It is just starting to give everybody, including the industry and the hubs, some sort of dashboard of how we are doing, because we have this great technical lead that I think has come out of that convening and collaboration. But if there is anything that is going to need mass collaboration to break into industries, I think it is quantum technologies.

Professor Dawson: Perhaps I could just add, I think the benchmarking is also important to build awareness of the level of investment in this area that is happening around the world. Many countries are putting millions of euros, dollars equivalent, on the table. I think particularly in the Far East we are aware of immense investments.

Q185 **Chair:** China. What other countries do you—

Professor Dawson: China in particular, in the multi-billions, as public information would have us understand. We have seen already the impact of that, for example, in the quantum area linked to space.

Chair: Thank you. Do you want to add anything, Richard?

Dr Walker: If I was to add anything at all—and you could perhaps come back to it—just for benchmarking, it is to look at the requirements of the industry and skills are something we touched on over lunch and it was mentioned again earlier.

Q186 **Chair:** Martin, you have obvious collaboration with Germany, which is often thought of as being successful at commercialising scientific strengths. Your organisation is affiliated with a German innovation network. What could we learn from Germany or other international comparators to help commercialise quantum technologies—or do we not have anything to learn?

Professor Dawson: There are always things to learn internationally. The key lesson from the German system is that this valley of death, this innovation space that was mentioned earlier, is something that needs sustained investment over decades to really address. The Fraunhofer network is a huge organisation in Germany, as everyone knows, a couple of billion euro a year and 25,000 people in over 70 institutes. That has not come into being overnight; it has taken 60 years plus. Where we are rebuilding what a colleague calls this connected tissue between academia and industry in the UK, we have to be thinking for the long term. Obviously in the quantum tech area, things are moving quickly. Fraunhofer CAP in the UK are already active in that space but we need to be thinking about how this longer-term development takes place.

There is also the industrial landscape in Germany with these family-owned mid-sized businesses that are again often engaged closely with Government and are supported for the long term. They are part of that whole sort of infrastructure, the supply chain, which works very effectively on a national level. I think there are lots of things to learn from Germany.

Q187 **Chair:** How different is the commercialisation challenge in quantum technologies compared to other sectors in the past or is it not different, ultimately?

Dr Malcolm: It has many of the same elements, but I think the complexity of the technology and the diversity of different skillsets required is in the extreme. We do not wake up one morning with a quantum industry. It has to be a long-term series of investments from everybody around the table who wants to participate as part of a quantum industry.

Q188 **Chair:** Presumably that means it absolutely needs collaboration between Government and academia and commerce?

Dr Malcolm: Yes, I think it does, and in as long term and long view as is possible for these types of things. If we take something digital, many elements that are touching society just now seem quite recent, but the digital journey has been a 70-year journey to get to the point we are at just now. We know that the speed of pace and change is increasing. Some of these systems that are being described and are being operated in the research environment are ultimately still very complex systems. We need to have the basic components, the supply chains, the integrations and the end users all lining up together. I think it is that

longsightedness and it is a very multiparty sport to bring these things together.

Chair: Are there any other contributions to that or are you happy with the answer that Graeme has given?

Professor Dawson: I would refer back to Erling Riis's comment about quantum inside. A lot of things ultimately for industrial organisations will be black box solutions, where it is when you look inside a quantum technology, but it is providing a particular benefit in terms of the business that they do not necessarily need to know the details of.

Q189 **Stephen Metcalfe:** During the last session, I was interested in developing a supply chain and we talked about its importance. If we are to develop or support a wider-growing supply chain, some of that will come through start-ups and some of that will come through spin-outs. Are there any particular challenges that face start-ups who want to start up in the quantum technology sector?

Dr Walker: It can potentially be a very long journey to get to some end goal in the quantum space, but something I would reiterate—this came up earlier as well—is that it is a journey that can have many stepping-stones along the way. It is very important for the way the funding calls are structured, for example, in the programme to reflect and to understand, and if we are targeting some kind of longer-term goal, to keep in mind that there can be many interim steps that can be commercialised in their own right. That should not be viewed as a negative thing. Sometimes you are slightly apprehensive with these projects of being seen to reach a commercial outcome too quickly, even if that is just one small step towards some kind of longer-term goal.

Q190 **Stephen Metcalfe:** Is the main challenge being patient, I suppose?

Dr Walker: It certainly can be, particularly with semiconductors. Computing is an incredibly long journey but there are many steps to interim products along the way.

Stephen Metcalfe: Would anybody else like to add to that?

Professor Dawson: We are very fortunate in the UK to have a very energetic and active SME environment, if you like. In the photonics area, for example, I think 75% of our companies are SMEs. These organisations, in our experience, benefit tremendously from the support that is available from Innovate and other programmes. That is often the way in which they can continue to do their R&D. I think this is really important to emphasise and that resource needs to continue to be made available to those organisations in co-funded form via Innovate.

Dr Malcolm: I think programmes like Innovate, they help convene the various parties over developing the supply chain, they help to capitalise and lubricate the processes of getting started. The continuity of programmes is important here, because at each step that Richard

mentioned, you need to get together to take the next step. The continuity of that supply is really important.

Q191 **Stephen Metcalfe:** I am getting the sense that there is quite a positive view of the ability to start up and that there is an appropriate amount of support.

Dr Malcolm: The gap that was identified in the previous session around the midscale stuff is where it really starts to get more difficult. It is quite easy to get the technologies started and moving and get support around those. I think maybe one of the unidentified areas is around what happens in the middle. What is that valley of death? It turns out it is a series of valleys of death, because you are breaking through the ideas to the full productisation and I think that is an area where you move from start-ups to scale-ups. That is a particular area where I think we need to look at how we get more collaboration in that space and we get more cases of success.

Q192 **Stephen Metcalfe:** Does the European Investment Fund play any part in that at the moment?

Dr Malcolm: Potentially it can. I think the scale of things in that sort of phase are commercial entities struggling with development capital to develop a commercial organisation, working capital to grow the existing contracts it has. It is often maybe working from a scientific marketplace into an industrial marketplace and there is marketing and business development in there as well. It is different forms of capital to support and that is why I said it is different valleys of death, because you are doing a number of different things at the same time.

Q193 **Stephen Metcalfe:** One of those forms of capital is patient capital, presumably. Do you think the Government's response to the Patient Capital Review is going to help the sector?

Dr Malcolm: There are a number of initiatives. One of our investors is the Business Growth Fund. That represents, over the last half a decade or so, a new way of taking a more patient capital outlook on things. I think that and some of the elements of the Patient Capital Review to look at how that scales are very encouraging. One area the UK tends to focus on is growth, where there is big growth capital. Some of the things we are talking about move into not just market risk but technical risk, so how we look at the increased focus around areas where it is patient but it is also a higher-risk profile is probably pertinent to quantum technologies.

Dr Walker: I would completely agree with that, Graeme, yes. I would add that a key thing for us is the support that has been available through Scottish Enterprise, which is fantastic, through the Innovate UK programmes—it has really helped our business to make steps forward, increasing technology readiness level and getting things closer to market. The further you can go down that journey perhaps before taking investment in, the easier and more attractive the proposition is. That is a crucial aspect. It is not just availability of money, but supporting

businesses to perhaps get to that first step so we are in a stronger position.

Professor Dawson: An element that comes in here as well is the sense and the importance of place. Local clusters and small companies often are embedded in a regional environment and also are interacting with other companies and the local universities. That is an important part of the national strength and you have seen evidence of that today from the Scottish science sector, for example. That is why in a sense there is a supply chain self-assembly, as long as we can give it the right support and encouragement.

Q194 **Chair:** Before I bring in the panel, David Connell, in his review of the Small Business Research Initiative, made the case for a reasonably substantial central fund, which could be used to help address the problems of valleys of death and so on. Is that recommendation one that you would endorse? Do you think it is an attractive approach? His view appears to be built on what has been done in the States. Any views at all?

Dr Malcolm: I think David Connell's view is a very well-informed view. He has looked at it from the UK's investment and venture capital community, so he is very aware of the capital that is currently available. He has then done a great job benchmarking that against other elements. The conclusions that he reaches on how you make sure that it is continuous across the whole journey that we talked about earlier, it identifies the quantum layers that we have seen growing two technology companies now. It is generally the bit in the middle; it gets really tough around the middle. By the time you get up to the high TRL stuff, people are going to buy it, they want to integrate it and incorporate it.

I think quantum has a unique extra bit, which is there are no existing integrators at all. There are big integrators in automobiles and aircraft and spacecraft and all those things. They want to use it, but we need a critical mass of early integrators there. I think that is the type of mechanism you will find that David has proposed addresses. He is proposing the systematic things and the example of the US and Government contracting and military and defence spending covers that area. That is the gap that perhaps encourages some of the problems that we have seen elsewhere.

Q195 **Carol Monaghan:** Graeme, you have already said that this industry needs a long-term series of investments. How would you describe the current stage of development of UK quantum technologies and what should be the next steps?

Dr Malcolm: I would say that we are developing a position of global leadership, not just in the programme, but in some of the emerging industrial applications. Our studies have shown that there is probably a handful of companies that can say that they can seriously integrate quantum technologies on a commercial scale so far. It is still very early

days, but I think the UK hub programme has propelled that. It is starting to create the joined-up supply chains that we have there. It is very difficult for Government to make very long-term elements but even at the signposting level and the level of us discussing this as a national priority, I think that can help a lot.

We were very impressed in Canada, where from their Premier down the Government has really strong knowledge of quantum and the effect it is going to have in their local economy. Martin mentioned China: they have quantum leads into their next 10-year plan and their 25-year plan. At whatever level we can do it within the local environment of starting to take that longer-term look, and very far out, it is really just for debate and alignment. The closer in we get, it needs to be more actionable. We have broken the national programme down into stages and we tend to be focused on the next stage, but I think we need to raise our eyes towards future stages to get proper buy-in.

Carol Monaghan: Richard, did you want to add anything?

Dr Walker: I would absolutely echo that. If you are looking at the state of the sector or the industry, high-growth technology businesses are just phenomenal drivers of the economy. Within that, photonics and the quantum community that that is part of, they are just phenomenally productive. Ask Graeme about his productivity for employee numbers and it is just stellar, what the sector is producing. It is a case of thinking, "What do we want to do here? Are we trying to create the next set of businesses of scale and how we are we going to do that?" You cannot scale up businesses you do not start, so it is then supporting fully the system of the start-ups to scale-ups.

Carol Monaghan: Martin, did you want to add anything or just agree?

Professor Dawson: Just to echo what has been said. We have had a very active early first phase in the national programme, where organisations/companies that had some familiarity by and large with the technology have bought in very quickly and the interest has been building up. The challenge is still to show that the quantum tech range of break-through applications can really be embraced by the larger organisations and that requires the steps in the supply chain to be built up, but the larger commercial challenges can be the answer to that.

Q196 **Carol Monaghan:** How close are we to having a standardised supply chain and do we need suppliers to be based here in the UK?

Professor Dawson: We have many of the relevant suppliers at the component level certainly in the UK. On laser technology we are very strong. That is represented here in the photodetector side; there is a range of activity there too. I think the software, the computational systems, assembling all these things together into a sub-system of system solutions, these are the harder challenges.

Dr Malcolm: That is the critical gap for quantum; we need some early indicators that then link that through to the big sectoral integrators that already exist. That is the opportunity for stage 2. We have said that stage 2 is focused more around the industrial leg and I think the thing that will let us build that the best is to do that at the integrated level, because the first countries that can create integrators can scale up. For example, in the European Union flagship programme, there are 20 companies in the advisory group and 18 of them are the big European industrial companies. They say at this stage that ultimately they want to incorporate quantum technologies, but they do not want to build them themselves at this stage. You need some companies and some collaborations that are going to bring these things through, as we heard, for communications or for sensing of computing, to a point of demonstrable adoption that they can then move on from.

Q197 **Carol Monaghan:** Again, it probably ties back to what Erling said earlier about they need it to do something but don't necessarily need to know the ins and outs. Do they have enough co-operation just now between the industry and the standards bodies to develop these supply chains?

Professor Dawson: There are a lot of links between industry and standards bodies through the National Physical Laboratory, through our IEEE standards and so on. I do not know how much of that is specifically quantum; I think it is largely based around the emergence of 5G, for example, and things like that. This is one area of particular aspects that are relevant to quantum and they need more focus on the standards side and engagement.

Dr Walker: It probably varies a little bit, depending on the sector that you are looking at. Something like a communications infrastructure, it is incredibly important that it is standardised, whereas areas that are more product and single point of use based, it is perhaps a slightly different question. If the electronics industry wants a part to become standardised, it then tends to become a race to the bottom and competing on prices and it tends not to be a way that the UK industry comes off so favourably in the long term, so it probably depends a little bit on the area that you are talking about. I can certainly understand the need for that in comms.

Dr Malcolm: We have a unique situation where the Standards Lab is an early adopter of these technologies to make, for example, ultra-accurate time standards for internet time, for financial services and those things. An advantage for stage 1 of the programme is that the National Quantum Metrology Institute has been part of many of these projects, so it is well in there. Again, that is potentially an ongoing area to build leadership on, because global standards are something that we have learnt a lot about in the UK and it will be really important for the rollout of quantum further down the line. I think the involvement of the National Physical Laboratory and the Quantum Metrology Institute really helps with that and is baked into these two ideas at this stage.

Q198 **Carol Monaghan:** In your written submission you talked about the

opportunity for Government to support projects that had societal impact in order to demonstrate the applications and potential of quantum technologies. Could you give us some examples of what you are talking about, and do these stretch beyond defence applications?

Dr Malcolm: They do. Some of the technologies that are being worked on—the likes of QuantIC on chemical sensing—are now getting deployed on ESA missions to look at the environmental health of the planet. That is a major pull-through of this precision light technology there. When we look at potential things like quantum computing, when we can build moderate scale quantum computers to do a 1 with 50 zeroes after it computations in a microsecond, we open new areas of computation. The prototype systems have been used in the likes of the national hub at Oxford in quantum computing and in customers of ours at, for example, the University of Innsbruck to demonstrate the first generation of these quantum computers that can go beyond the problems that can be solved classically.

When you start to think about societal problems, some aims in things like perhaps healthcare, how could quantum help the NHS and how could it help medical science? Could we start to model big challenges, like what causes protein misforming in the brain that creates some of the big societal problems like degenerative brain disease? How can we use quantum for imaging these applications? In many ways, as Erling said earlier, nobody cares if your medical device at the end is quantum or not, but they care that it can start to solve some of these bigger problems.

That is an area where a particular advantage of place here in the UK is these clusters, but it is also the fact that the UK geographically is compact and has global excellence in things like medical sciences, so we can get these collaborations going. We can get around the UK in a day. If we travel to the States, it is a week for the east coast, a week for the west coast and a week for the middle and you have missed out big parts of it as well, so there are connected areas here that helps.

Q199 **Carol Monaghan:** Do you have medical research in the same campus as you?

Dr Malcolm: We do. We collaborate with the likes of the Beatson Institute just across the road from us, so those sorts of things are great potentials that help us get match-ready as well in terms of the quantum technologies for commercial applications.

Q200 **Chair:** Is not attention being given—perhaps with the involvement of social scientists—to the longer-term vision and the impact that these technologies could have on society and the risks and the dangers as well? We have heard about the apocalypse that we are trying to avert, but there is also potentially a dramatic effect on society of these technologies in the longer term. How much thought and attention is being given to thinking through that vision?

Dr Malcolm: From my perspective, some of this stuff is a bit of a dawning realisation, that these things are now technically becoming real and we have to look ahead more at what is happening there. What the UK has to offer is its long experience of thinking of ethical issues and societal issues. We have seen some areas of the world saying, "Come here to do your science, because we do not have such a big ethics issue for you." I think, "Wait a minute. We have to take a better approach to make sure this type of technology is responsibly developed."

But back to your question, I think for phase 2 and beyond, the convening that has happened in phase 1 has really been around feasibility. The next stage has to start to think through the impacts and the responsibilities that we bear in taking these technologies through to realisation.

Q201 **Chair:** So that should be part of the focus of phase 2, that we start to think about the impact?

Dr Malcolm: I think so. When I mentioned the triangle of the different parties involved, we have seen cross-government involvement, including the national labs, the Ministry of Defence, the NHS, the Department for Transport and the National Centre for Cyber Security. We are seeing quite broad early stage engagement but I think that conversation just needs to be on the agenda as an item throughout the future of the programmes.

Professor Dawson: I would maybe add that the scientists and technologists themselves have done their best, I think, with a lot of aspects of the social side of these developments. We need to consider and write these things in our research proposals. They have been embedded in the way the hubs have been operating to date but of course we are bringing just one perspective to bear. The point that you made about social scientists and others and that wider engagement is very important. It is often economists, for example, that tell us important things about how innovation works and they are able to get the technologists to see things that they do not necessarily see from the inside. These wider perspectives are very important. I think they do need to start to be broadened out in the discussion of these issues in the next phase of the programme and beyond.

Chair: Did you want to add something, Richard, very quickly?

Dr Walker: If history tells us anything, technology is hard to predict.

Chair: Thank you for that helpful comment.

Q202 **Bill Grant:** Just looking at the next phase of the national programme and what levels of funding the Government should seek from industrial sources, I think, Martin, in your submission you advocated removing what I believe to be a 30% limit of Innovate UK's project costs that can be accrued by non-commercial organisations. Would you stick to that gun and stick to removing it altogether, or would an increase in that percentage be helpful?

Professor Dawson: It is potentially different for different types of organisations. Fraunhofer is a not for profit independent RTO and as we have grown with the national programme to date, what we find is that the partner organisations, the companies that we are serving, want us to do more and more for them in these programmes. We are very well-positioned to be able to do that, but the 30% cap on total project costs is very restrictive on what we can do. I think it is essential for us. It also tends to predicate against multiple SMEs getting together or getting multiple RTOs getting together as part of collaborative programmes. You are constantly thinking about the total balance of resources.

Q203 **Bill Grant:** So that percentage cap restriction is not helpful, you are saying. It's boxing out opportunities for us?

Professor Dawson: For Fraunhofer UK, that 30% limit is a real inhibitor for what we can contribute in terms of supporting the company partners in these programmes and also it is an inhibitor for us working collaboratively with other likeminded organisations as well.

Bill Grant: I sensed a nod of the head there, Richard.

Dr Walker: Yes, and it is something we have bumped into on our projects. I can understand the perspective that perhaps treating RTOs separately from academic partners could be an alternative to changing the number, to allow an RTO to join almost as an industrial partner to develop the industry. Universities love to charge slightly interesting overheads to an SME, so there is a consideration of obviously not wanting a project budget to be gobbled up by the academic partners but of course recognising the extraordinary value that partners can bring. If that limit is to be increased, we need to perhaps consider that the EPSRC or the Hub outreach budget does not allow industry to take part, so maybe both could be more flexible.

Q204 **Bill Grant:** Could it be made easier for SMEs to get on board? Are you suggesting that?

Dr Walker: Yes, perhaps easier for businesses to take part in the Hub-funded outreach projects, as well as making it easier for academics and RTOs to take a larger role in the Innovate UK projects to keep a balance.

Bill Grant: Any thoughts, Graeme?

Dr Malcolm: In particular areas it is a key blocker. If we take an area like quantum computing, among the SMEs I think we have the skills, the capability and the ambition to do that, but as Erling Riis mentioned earlier, the scale of those sorts of programmes needs to be that next step in scale, because it is a bigger undertaking. The SMEs each become more stretched in their participation in a project like that, as do the universities, because we are now talking about £5 million, £10 million, £15 million programmes. I think there are going to be a few of those key, almost lynchpin, programmes that are going to suffer most from that activity.

Often the small programmes, as we heard, can somehow find the right mix or you swap out a partner to get somebody that can bring 30% to the table. My concern particularly with the 30% limit is that if we wanted to put together a consortium to really move through quantum computing or something like that, which is a big ambitious goal, then matching funds becomes beyond the reach of companies that are still on their scaling journey.

Q205 **Bill Grant:** Staying with Innovate UK, they have funding competitions. Are they of sufficient scale and do they follow a clear enough strategy to develop, as we aim to do, a UK quantum industry? Are they in the right direction? Are they asking the right things? Should they be throwing their net wider and maybe favouring quantum technologies and boxing out other technology that may be equally innovative and they are maybe not getting the opportunity?

Professor Dawson: The point that I would make on this is there have been five themed calls by Innovate UK to date in quantum tech, each of them very heavily over-subscribed. I think everyone involved would say that they have been a tremendous success. This is a key mechanism that has drawn the SMEs and others together and really knitted the national programme together in terms of the university effort and intermediate organisation effort linking to companies. We are in a kind of transition phase at the moment that is a little bit concerning, I would say. The main funding on the table at the minute is challenge-led, coming through the Industrial Strategy Challenge Fund.

This is fantastically welcome, of course, and as Graeme mentioned, it is allowing these much larger and more ambitious programmes to come together but it potentially predicates against the almost responsive mode, new developments coming in and the possibility of drawing the industry engagement net wider. We have a concern that, at the moment at least, the last of those lead programmes is under way—it finishes in the spring of next year—and we would say there is a funding gap in the UK themed calls that are not prescriptive.

Dr Walker: I would echo that. I think you need a variety of both size and scope projects available to support industry at all different levels, yes.

Dr Malcolm: Sometimes I feel that there is an opportunity to benchmark outputs in terms of economic activity. Richard mentioned earlier that our business creates revenues of over 200K per employee. That is similar in our technology company based here in Glasgow to the City of London in terms of it. If we look at the value proposition to the UK economy, it is very high, so you would want to just make sure you catalyse that as quickly as you can. As well, the journey sometimes is not a continuous one, so Innovate and the Government can see their required outputs up here but a company might say, "We need to go and bag the space industry before we get to there."

The call-based stuff is direct line of sight now but, from a company's perspective, the more company proposed or the technology push side of things can be an important part of that journey to get to mutual end goals. Having the call-based stuff is useful, but I think having stuff that supports journeys that are on a mission and are creating economic value is something that can be looked at as an addition to the current process.

Q206 **Bill Grant:** Just the flexibility embedded with the competitiveness.

Finally, if I can pick up on a remark you made, which I wrote down here. Graeme, I think you said that Innovate UK was helpful and did lubricate progress. As a Committee, we sense that Innovate UK had some bureaucratic issues maybe earlier on in its progress. Do you think these bureaucratic issues have been resolved or is it still a tad bureaucratic?

Dr Malcolm: I mentioned earlier that for quantum, pace is more important than for anything else that we have ever done. What we see is that as the progress gets more material, other countries are bringing down the barriers facing their companies. Innovate UK manages this as part of a portfolio of different technologies. There is maybe a little bit of a 'special forces' approach needed for quantum, because of the timing and pace requirements, so that we could reduce the processes that are often very good for other sectors. We do stuff still in the medical sciences that can take many years to get there. The processes there are very well-balanced for that type of thing but I think the pace and urgency, we would say lower the bureaucracy, try to make it as quantum and company-friendly as possible.

Q207 **Bill Grant:** Am I sensing you are suggesting that academia and industry are going at a better pace than Innovate UK itself?

Dr Malcolm: Yes. What we are seeing, and maybe this is a way of expressing the success of the UK programme, is we are now shipping things that three years ago—I have done this technology for 20 years—I thought were unimaginable, that the progress would be made to the point that we could demonstrate and ship things. The pace of change is really strong for people that are deeply embedded in this technology, so ensuring that Innovate UK can increase its pace, I think it needs that feedback mechanism and the general urgency and sponsorship from Government that they should be increasing their pace here.

Bill Grant: A sequential nod there.

Professor Dawson: Yes. I think we have seen practical issues with delayed starts and of course there is a fixed end point to these programmes. They are usually a year, 18 months. It is a very short timescale where you are wanting to make very quick progress. Of course that just creates extra challenges if there are delays. Innovate is a fantastic organisation and it is trying to do a lot of different things, but certainly it would help if some of these aspects could be smoothed over.

Q208 **Carol Monaghan:** Martin, you have already said that Innovate UK, when

they put out a call to companies, were overwhelmed. Do you feel there are suitable mechanisms for the industry to feed in directly to the national programme?

Professor Dawson: Industry is already very widely involved in each of the hubs and I think that is important. QuantIC, for example, has used its partnership fund for direct engagement with companies. Each hub has had company support, and there are advisory boards, so there are certainly lots of avenues for the hubs to get industrial perspective and engagement. The same is true on the UK National Strategic Advisory Board as well, which takes industrial input. So in general, yes, I would say so.

Dr Malcolm: For me, an exact example was the unified way that UK academia, Government and companies went to Canada and engaged in a broader collaboration there. It was not like everybody was needing to be drawn together to the same agenda, we already had it through all the kind of participation and stuff in the hubs. I think that has been—

Q209 **Carol Monaghan:** One of the challenges in this area is the number of SMEs working in it.

Dr Malcolm: That is certainly a challenge but it is also perhaps one of our greatest opportunities, that we have enough people. It is a bit like photonics, we will have to do things differently, but we have now created more jobs in photonics than in big pharma, as Sir Peter Knight mentioned in a previous session. There is more potential from a similar thing in quantum, where we will have to recognise the fragmentation of the thing but when we amalgamate it together it is very meaningful. Your question on engagement is how do we make that as well-suited to SMEs to participate in as the hubs. I think the hubs have worked really hard—and all their partners—to pull it together and make it friendly for SMEs.

Dr Walker: Likewise, I would say I hope the Committee can see the number of SMEs in this sector as an opportunity and an asset rather than perhaps a challenge.

Professor Dawson: Perhaps if I just briefly add one thing I think is important: the success of the National Showcase event that has been held each year for the last three years. This has been a crucial forum for presentation of the outputs of the whole national programme, but also to give that wider engagement and allow the public, journalists, press and others, but also the wider industry, an opportunity to engage.

Q210 **Carol Monaghan:** What we are hearing is that one of the challenges, I suppose, is the number of SMEs doing slightly different things. Does there need to be one voice? Is the industry developed enough to have a sector council like, for example, we have for the food and drinks sector? Who might be represented on such a council?

Dr Malcolm: I was going to say it is probably not that well-developed, but it needs to do it anyway. I think that is an important thing that we

should do, as you suggest, at a formative stage. We do that to an extent through the hubs and there is an industry advisory group around the hubs, but perhaps for the next phase, industry stepping more into the spotlight to move forward is probably an excellent idea.

Professor Dawson: Given the strongly photonics-linked nature of much of the quantum tech area, we have the Photonics Leadership Group in the UK, which is an industry discussion organisation. I guess it has taken on some of those responsibilities but certainly things are probably getting to the point now where we need to think beyond that.

Dr Walker: Likewise, it is ensuring if there is going to be representation, how do we get a broad representation of many of the constituent members of that sector?

Chair: Thank you very much indeed. We have 16 minutes for the last two questions.

Q211 **Bill Grant:** In 2016 there was a report for the Office of Science on quantum technologies and it recommended innovation centres. What should these innovation centres do for business? What should their role be to make life easier for business and to improve the quantum technologies? What do you expect them to do for business?

Dr Walker: There was an interesting comment about them being centred around key assets, which I think is a very interesting idea. One area is how we can better provide access to certain key facilities, particularly capital facilities, to the community of SMEs, which would not otherwise be able to justify the investment for a significant cleanroom or whatever the equipment is.

Dr Malcolm: In a lot of the evidence on other things, we have seen that the mid-TRL level is the pinch point. I think one of the innovation centres should be focused around integration and that will need facilities, it will need expertise and it will need to bring supply chains together. The thing that is unique about quantum is that we need to demonstrate integration to access the different industrial next-level-up integrators, to get to the full quantum subsystems; I think it is important. A place that we can facilitate the interactions that are still very much a pull-through from the science base, but has enough integration capability to get it out the other end of the TRL sector level.

Q212 **Bill Grant:** Innovation centres should be nearer business and nearer the marketplace?

Professor Dawson: Yes. What I would say is I think we have to recognise that there are organisations in that space already. Fraunhofer UK is one of them, it is an innovation centre; the Catapults as well, the compound semiconductor application Catapult; the satellite systems, these all have capabilities relevant to quantum. The key thing with this next phase and the development of the specifically quantum innovation centres is that we position them technically correctly and organisationally

correctly, more on the industry side for sure, the integration side, facility side, but I think the challenge to Innovate in developing the case for these is to get the model right and yet balance that against perhaps not being too prescriptive, so that the community can respond and come up with the ideas.

Q213 **Bill Grant:** The innovations, despite the health and safety risk that was mentioned already.

Dr Walker: Flexibility is a key theme across the board.

Chair: Thank you very much. That is incredibly disciplined. Stephen.

Q214 **Stephen Metcalfe:** I want to go back to the issue that was raised at the end of the first session, which was around skills and how much of a challenge that is. We talk about there being a skills gap in the UK. Have any of you experienced problems recruiting? If so, at what level is that? Is that postgrad, Master's, PhD? Just give us a flavour of where the actual challenge lies. Richard.

Dr Walker: I would probably say across the board, not just in the quantum sector. Talk to any of the other businesses along our corridor in the incubator trying to find software engineers in Edinburgh, there is a whole host of problems and it is really at every skill level. The question is, when we have so many foreign students coming over and getting a first-rate education, why is it that we then send them off home to compete with us afterwards? How can we better retain the people that we are educating in our fantastic universities to come and deliver for UK industry?

Dr Malcolm: Out of 100 people, our business has almost 60 PhDs and each one of those is handpicked over a long period of time, so there is definitely a challenge there to be met. As the national programme has grown up, that challenge has become more intensive because there have been more positions globally. Another area is in the specialist MScs, the Master's degrees. There was a joint Master's course between Heriot-Watt and St Andrews that we used to get a lot of students from. Understanding the future requirements of industry to help the funding processes there would be a very useful thing, because that MSc lost its funding. I know that we compete with the defence industry, so Thales and Leonardo, for those types of skills, but collectively we could say, "Hey, in two years we will need x number of people" but there is not a mechanism to feed that into.

The other area I think that we are at a global disadvantage on is that mix between commercial and technical skills, where more education in the management of technological innovation and the commercialisation of it would help a lot. That is the really rare bit: we struggle to find people that can close a £20 million business, because we need that detailed mix of skills there.

Professor Dawson: The UK universities are very good at training highly qualified people for these areas. In the quantum case, they are still predominantly from a physics background and I think we are all aware that quantum engineers are very substantially required. There are doctoral training centres that are aligning themselves to training such quantum engineers and that is a really crucial thing. We have to increase the volume of people coming through those programmes.

Q215 **Stephen Metcalfe:** Has it hampered growth in any of your organisations, the skills gap or lack of people at all levels, PhD and—

Dr Malcolm: Specifically in some levels, it takes us six months to get somebody productive in the business from hiring them, because we are doing some of the things ourselves to supplement what is available in the general market, so that gives us a six-month productivity downturn.

Q216 **Stephen Metcalfe:** That dampens your ability to expand and to grow. Thank you, that is very clear and very useful for the record.

We talk a lot about alternative ways into sectors, one of which is the apprenticeship route. Is the quantum technology sector an appropriate area to promote apprenticeships and are there any examples that you could share with us?

Dr Malcolm: Increasingly so. You start with the research phase, where you need very high-skilled people but then, as you start to deploy the technologies, you open up the pool to the technician elements, the manufacturing people. We are part of many local initiatives to see high-value engineering and manufacturing technologies pull through, and that is the perfect ground for apprenticeships and longer-term 'learning on the job' types of upskilling in the workplace.

Dr Walker: I would agree with that. Less at the start-up end of the spectrum but certainly as businesses scale up and go into manufacturing, absolutely.

Q217 **Stephen Metcalfe:** Are you aware if there is an appropriate standard or framework already in place to support an apprentice, so that you could train them to something?

Dr Malcolm: Yes. Increasingly, and as another advantage of the hubs, universities are having a very open dialogue on the skills that we need. We have more course engagement than ever before.

Q218 **Stephen Metcalfe:** One final question from me: recognising that there was this identified skills gap across the whole economy, that the jobs of the future are going to be more technical and require higher levels of skills than perhaps the jobs of the past, what should the Government do to help people understand new emerging sectors like quantum technology? You talk to someone about that in schools and it is unlikely that the majority would understand what we are talking about. How do we have that national conversation?

Dr Malcolm: I think you do have to start in the schools. We do this thing called Founders4Schools, where we just go in—explaining something to an 8-year-old or a 10-year-old is a real challenge, but it means that you get very succinct about it. What you are aiming to do is just give them a starting point of interest, because what we see with the internet is everybody can access lots of learning and lots of information, so you can just get those sparks. I think just a very top-level broad awareness and the demonstrators of the UK Quantum Programme, it is just getting it more broadly out there gets that spark.

Professor Dawson: The scientific community certainly take these responsibilities very seriously and we are encouraged again in our grant proposals to identify how we will facilitate outreach. Most of us do give public lectures, write general articles for the public, help create demonstrators for science centres and the like. More of the same is certainly very important, I think.

Dr Walker: I would echo what has been said, yes.

Q219 **Stephen Metcalfe:** Is that public engagement done because it is a requirement of the grant or because you see that this could hamper the sector's growth and potential in the future?

Professor Dawson: I think it is what academics want to do anyway. We are recognising collectively that we have more and more responsibility to do just that, so it is something that we are very willing to take on and people are trying their best to do it.

Stephen Metcalfe: That is on the record, then. Thank you very much.

Q220 **Chair:** Just before we finish, given that we are doing another inquiry at the moment about the immigration rules that are necessary or that would benefit and facilitate science in this country post Brexit, do you have any particular points that you want to make, very briefly, so far as quantum technologies are concerned and the ability to bring the best people in at whatever level from other countries, either Europe or elsewhere?

Dr Malcolm: A third of our staff come from overseas. They add diversity of culture, educational system, scientific background and experience. It really adds to our ability to go faster in this demanding environment. Our ability to attract people to the UK has been a key part of our growth. If we look to areas like Tech City and the digital economy and the ability to fast-track those introductions, I think it is important to the UK competitively. We are in a fast-moving area.

Professor Dawson: The freedom of movement of technically qualified and scientifically expert people is crucial. It is absolutely what keeps the whole system operating. We are all part of a global research environment and we benefit from experiences that have been gained elsewhere being brought to the UK.

Chair: Do you agree, Richard?

Dr Walker: Absolutely, yes.

Chair: Thank you to all the witnesses in the two panels for your time this afternoon. It has been absolutely fascinating. We appreciate your engaging with us. Thank you, Erling, for your hospitality this morning. We had an absolutely fascinating time at Strathclyde. Steve, thank you as well for your hospitality and allowing us to sample really excellent Scottish food in a very attractive place. Thank you to all of you for being here. I thank the Clerks and the other staff for facilitating this. It has been a very good exercise, escaping from Westminster. We should get out more often, is the probable conclusion we should reach from that, but thank you all very much indeed.