Chapter 12
Scientific Advice: A Personal Perspective in Dealing with Uncertainty. An Interview with Prof Dame Anne Glover, in Conversation with Tim Bedford

Anne Glover and Tim Bedford

INT: **Anne, the purpose of this discussion is to understand more about the role of expertise in the scientific advisory mechanisms for government and more specifically about the role of a CSA as an intermediary between the policy world and the science world. Obviously, your CSA roles have given you unique experience of interacting at the highest levels with public authorities. I'm sure there are lots of different aspects that we could cover, but for the purposes of this conversation I am particularly interested in your general experience of the use of scientific expertise, the expectations that government—whether civil servants or ministers themselves—have of scientific advice mechanisms and how those match expectations of scientists, and the ways in which both groups do or do not articulate uncertainty.**

RES: I think it's important to say that in the posts I've held, where my responsibility has been about providing scientific advice to governments, it was the first time government had such a role. Although I had a broad network to rely on in terms of procuring advice and helping to synthesise that advice to provide expert judgement, what was not expert was the receiving end of that advice. The value of expert judgement is two-fold. One part of it is how you procure that expert judgement including what methodology you use to approach that, and the second is the capacity to absorb and use that advice. For example, the recipient of the advice may already have a bias regarding what they want to hear, often referred to as policy-led evidence, which is a difficult thing to overcome when you are trying to provide evidence in order to underpin

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an evidence-based policy. In my experience, not in every case, but there is a very strong, probably philosophically led, approach to how you should go about procuring evidence. It starts with the question you ask. A fictitious example I might give to illustrate the point is that a European Commissioner might be thinking over the weekend: "I'm really concerned about financial instability within society, how people manage money and get themselves into debt and how this impacts more largely on banks wishing to lend in an inappropriate way, to very high risk to people who are prepared to take on debt". The Commissioner might be thinking about that whole issue and then decide "OK, I think probably one way of dealing with that would be to restrict the use of credit cards in the European Union and that would be a good policy announcement". Making such announcements could be regarded as one measure of success for a Commissioner. So they might come in on Monday morning and say to their officials, the civil servants, "Find me the evidence that the use of credit cards enhances the likelihood of debt amongst families that cannot hope to repay that debt". If there's expertise within the area then the officials will try and provide that, but more likely than not they won't have the expertise so they will go to a consultant to say "We would like to look at evidence implicating credit card use as a cause of financial instability" and what you get is a report telling you just that. This is an example of asking the wrong question which pre-supposes the answer you want to get.

INT: **So there are a couple of things bound up in that, one is the framing of the initial question, how narrow or how broadly you frame that question, and the other aspect of it is the fact that the politicians have got the right and duty to make their value judgements that they've been chosen to make surely?**

RES: Yes, but at the end of the day it would not be expert judgement if they just had a hunch so it's not based on anything. It would just be trying to camouflage a narrative of "I don't like credit card companies and I think they encourage unsustainable personal debt" by the procurement of biased evidence to confirm the hunch. [As a CSA] if you're not framing your request for evidence in a proper way then the person who is asking you for the advice can easily be undermined by being challenged on the relevance and diversity of the advice sought.

INT: **Is one of the wider roles of a CSA then, to try and help them frame questions in a better way?**

RES: Ideally yes. You want to understand the issues that are concerning politicians so that you might offer them as much relevant and useful evidence or advice as possible. An example might be a concern a politician had about the increase in number of people in hospitals with respiratory disease and their wish to understand why that was. The understanding might then offer some policy interventions to improve the situation

A good example would be around passive smoking where you might identify a linkage between the environment patients were exposed to and they are being admitted to hospital with respiratory disease. The evidence would

be built up to implicate exposure to second-hand smoke as being the primary cause of their illness. That would be a straight forward provision of evidence which would allow a politician to consider policy interventions to reduce the exposure of citizens to secondary smoke. A more challenging example might be where politicians don't want to hear the evidence because they've already decided what they want to do about an issue. A good example of that in Europe is that the vast majority of European citizens across all 28 Member States do not wish to have genetically modified food on their shelves and so the politicians would quite like to regulate against selling GM food in Europe or importing GM food for human consumption. But, if we presume that policy should be based on evidence, it is not possible to find credible evidence to support the claim that GM food is harmful. Politicians then might change the nature of the question to "can you be 100% certain that GM food is safe?" Now if you just ask that question my answer as an advisor would be "no" but you could ask a supplementary question which is "can you be 100% sure that non GM food is safe?" My answer would be the same "no" because I can't be 100% certain for either. But they want the uncertainty in the first case and they don't want to hear it in the second case, and so the political solution is to say that we don't have enough evidence to judge the safety of GM food. In fact, by any objective measure, we've got more evidence about the safety of GM food than we do for any type of food. This is a good example of trying to legitimise a policy on the basis of saying there is insufficient evidence, whereas, in other areas, policy might be made on the basis of scant evidence if there was a political imperative.

INT: **So do scientific advice mechanisms fear to tread in areas where there's a very strong cultural preference?**

RES: No, I think if you fear to tread and you alter your advice you're dead as a scientific advisor.

INT: **I wasn't saying you would alter your advice, but is it less welcome in those areas.**

RES: I think it is probably not welcome but the value in speaking to somebody who's seeking advice is to say that sometimes you'll like the evidence that is presented to you and sometimes you won't, but the evidence will be independent of the level of political bias or philosophical bias that they use.

INT: **But biases can sometimes arise in the interpretation of that evidence, or in the way evidence is extrapolated to new situations?**

It is also worth mentioning that science is not value-free either. Scientists have values, and we shouldn't pretend that we can be absolutely objective when it comes to the advice or the evidence that we put forward because we as scientists can also be selective in how we address evidence. I challenged my own approach to evidence after a politician gave me a book on unconscious bias saying "you might find this interesting". Of course, I knew about unconscious bias but I like reading so I read the book and it made me think. If I continue with the example of GM, then I realised that I've looked extensively

at the consensus of evidence around the safety of GM technology in order to produce new food varieties and I am convinced that it's as safe, if not safer, than any other technology we might use to produce a new variety of food, using conventional plant breeding technologies. What was interesting to me is that I recognised that if a paper was published that concluded that GM food is dangerous then I went through the methodology and every part of that paper with a fine toothcomb because it did not agree with my previous thinking and my judgement on the evidence that was available. But if another paper came out that said GM food is safe, I didn't go through it with the same degree of scrutiny. So that's why I'm saying my own values and confidence in my own judgement affected my approach. You have to remind yourself that both papers require the same degree of scrutiny or you're not doing your job as an advisor or expert.

INT: **In public debate, there is sometimes a resistance to accepting evidence, you might call a conscious bias, and I wonder what the underlying reasons are for this**

RES: Often people have very strong views that they haven't dissected in their own minds e.g. on GM. Someone against would probably agree there is no evidence against the technology but they might agree that it hasn't been used in a beneficial way. Many organisations against the use of GM raise issues like the impact on bio-diversity, increased use of herbicides, impact on small farmers. But these things didn't arise from the technology, but from the way, it was used by Monsanto. The technology is conflated with the business practice. The call to ban GM is a simple message that seems to be driven by this.

INT: **From a theoretical decision-making point of view when you're making decisions under uncertainty there is the separation on the one hand between the uncertainties which are supposed to be measured by probabilities and could be assessed by expertise or by experimentation perhaps and on the other hand the value judgements—trade-offs and so on—which are being made by the politicians. You are observing that there are biases on both sides which could affect the outcome.**

RES: Yes. You can get well-respected scientists who will take opposite views on topics where there is demonstrable uncertainty such as the impact of low levels of endocrine-disrupting chemicals (EDCs) in the environment. One scientist might say that we should ban all use of EDCs because the potential impact to humans could be very harmful and another scientist who would vehemently disagree because there is no evidence to demonstrate such harm at low-level exposure and that they are really valuable chemicals for society. They try to undermine each other's arguments and, of course, both groups are good scientists, but they try to discredit each other. None of this is helpful to the policymaker as they can choose what advice they wish to use.

INT: **So this is actually the scientific method in all its glory at work as run by humans rather than purist exponents of the scientific method.**

RES: Yes, it is run by humans. The evidence has a degree of purity around it but where it is synthesised into advice or judgement, other factors come into play.

INT: **So you just described very nicely there the ways in which scientists argue especially when they are within their scientific area. If they are pulled into a policy advice area where they know the purpose is to try and understand the level of uncertainty and to follow some kind transparent process, do they change behaviour?**

RES: They can select evidence or highlight uncertainty in order to pursue the hypothesis they favour. For example, think of a hydrologist who is expert in how water flows through rocks and they are asked about whether it is safe to allow fracking. If that scientist really doesn't want to see fracking perhaps because of a rationale such as "you shouldn't be using shale gas or any fossil fuels because it's polluting and I'm worried about climate change". Even although a scientist considers that in a particular environment fracking might be quite safe they may pull in evidence from other examples to allow them to say "ah yes it was demonstrated here that there was pollution of the water table by a fracking process". We should be very conscious of the selective use of evidence. So scientists, because they are human, can easily conflate things in their own mind which affects at the end of the day what they decide to say.

INT: **So how does the person that requires the policy get access to more unbiased scientific judgement?**

RES: Let me give you an example of one approach. There are two groups of reputable scientists who have diametrically opposed views about what European Union policy should be on endocrine-disrupting chemicals and I asked them to come and have a meeting with me on the topic, in the absence of policy officials (because I didn't want them trying to influence the policy officials by what they said). I set the agenda around defining what the issues were and examining the evidence to identify where there was consensus and where the disagreement lay. At the conclusion of the meeting, both sides felt able to sign up to a statement of what they agreed and where the uncertainties lay. However, two issues became clear. The first is that each group of scientists had a constituency and they were nervous that they would be seen as relaxing their views if they did not maintain their fixed views. The second issue was that both groups felt they had a role in suggesting what the policy should be based solely on the evidence they provided. At this point, I think there is value in a third party (this could be a CSA or an advisory panel with no fixed views or constituency to serve) assessing the evidence to draw out where the uncertainty lies and what the impact of that uncertainty may be. Based on the outcome of this, the policymaker can develop different policy options (possibly bringing in other non-science-based evidence such as economic impact, public opinion, etc.) each with an impact assessment. Ultimately, the politician will choose which direction policy will move and evidence will not be the only factor being considered.

Politicians find it very difficult to deal with uncertainty (and risk) in these situations. There's a famous quote from Winston Churchill saying that what he most wanted in life was a one-handed Chief Scientific Adviser because the problem with Chief Scientific Advisers is they always say "well on the one hand …." and that's not what he wanted to hear. He wanted to hear that the evidence is clear that he should do one thing or another. But most scientists are reluctant to talk in terms of certainty. Also, I think you should start getting worried if scientists or scientific advisors are setting the policy as, unlike politicians, they do not have a democratic mandate. However, society does pay for their expertise by training them so we should value the evidence and analysis they can provide.

INT: **So it's interesting that you said politicians don't like to talk about risk and they don't like to talk about uncertainty but when you look at things like the national risk register which we have in the UK that uses exactly that language of risk and uncertainty, so it does play quite a big role somewhere in government?**

RES: I think this is a slightly different issue than providing scientific advice. It is very important to have a risk register and some idea of how those risks might be mitigated. That could require direct action by the Government or could require a policy intervention, which should then be evidence-based. Quantifying risk in terms of likely impact is also crucial to allow the targeting of resources when the amount of resource is always limited.

INT: **So do things like the national risk register help start the conversation about risk and how you manage those risks?**

RES: Yes, but I can't ever remember a time where there was a public discussion around the national risk register although more recently, citizens have engaged and demanded more discussion around issues such as climate change. Climate change is an example of an issue that is very difficult for politicians because of the timescale surrounding the issue. It is a significant challenge to make difficult policy decisions that may result in substantial change for citizens in the timeframe of the electoral cycle in order to safeguard the environment for future generations. They face not getting the credit for their actions (e.g. banning the use of private cars) where the benefit will be felt 20 years down the line.

INT: **One sometimes feels that uncertainty is used to avoid a discussion around controversial issues, even when the risks are low. To support good public policy should we avoid framing issues purely in terms of risk?**

My biggest frustration in trying to drive evidence-based policymaking through the provision of scientific advice is the lack of transparency in the process. It is right that other types of evidence than scientific evidence should be used. These might include economic evidence, ethical views, political consideration, public opinion, etc. The biggest hindrance to improving the quality of evidence in policymaking is the lack of transparency about what evidence is used and what's not used.

So on the GM issue, how good it would be if in the EU and the UK ministers said "all the evidence tells us that this technology is safe and can be used and has been used safely, however, we also know that our citizens have demonstrated no demand for this technology. So given there is no demand, we will not approve cultivation". What that does is allow citizens to say "Oh, I've never wanted it but you're saying it is safe—is there any advantage to having it for me?". Then there might be conversations around reducing the climate impact of agriculture by not using any pesticides or herbicides which come from petrochemical manufacture but we could genetically modify the crops so that they were resistant to the pests in the first place so you didn't have to use the chemicals, you might call that something like GM Organic. You don't have to add chemicals but it's not a conventionally bred crop, it's gene-edited or genetically modified, that is an option, are you interested in considering that? This is the start of a dialogue and of course what you rely on is the expert judgement from the scientist to say how effective GM organic crops would be in reducing the contribution of agriculture to greenhouse gas emission.

INT: **And there must be a strong role for social science as well?**

RES: Social scientists are crucial here but not as an add on, as a fundamental part of the process.

INT: **It may be going off-topic slightly but things like the citizens' assemblies have been mooted as ways as dealing with kind of politically controversial issues, I wonder if they would have a place here?**

RES: Yes, actually it is interesting because Scotland has just introduced citizens assemblies and I am very much in favour of this. It has worked well in Ireland and in Denmark. The role of scientists would be to provide evidence and explanation to the assembly. I also think there is value in these assemblies being run at arm's length from Government as this will help the population have confidence in the debate being held. Trust in the process is very important. Evidence from other assemblies is that the wider population appreciate the time their fellow citizens are investing in the assembly and to get to the bottom of the evidence presented and they feel more open-minded to the recommendations coming from the assembly at the end of the process. I do like the idea of that we hear the citizen's voice because they bring a different view of the evidence and other values to the table.

INT: **You were discussing the fact that experts might have very different kinds of opinions about things. There is a school of thought in the expert judgement literature that says that if experts come together and they evaluate the evidence for long enough they'll eventually come round to sharing the same perspectives and even agree to the same probability assessment. Is that something that's reasonable or is the only way to get them to agree to lock the door and not give them lunch until they agree?**

RES: I've probably got more examples where people have very entrenched views about the evidence and the validity of particular types of evidence and so on. If they have an entrenched viewpoint, they are usually reluctant to be open to

discussing somebody else's view of the evidence. It's probably because by the time it gets to those discussions, views have become quite polarised. If you were generating the evidence in a laboratory and there was discussion about the interpretation of the evidence, that would generally be used in a positive way and constructive tension between the two might unpick the differences and improve the analysis. But we must understand that scientists or experts are also human and have human frailties, they don't want to be humiliated, proven wrong. They may feel they have a vested interest in their evidence being used and relied upon and their expert judgement being valued by a group of citizens. You must be wary about that.

INT: **So that's very interesting because I would have expected you to say, "as a professional scientist that scientists will do their best to be as objective as they can be" but what you're saying is that in many cases actually they're swept up, they're also political animals as well, so does that…**

RES: Of course, in an ideal world you would want scientists to be utterly objective but that's hard to achieve. They've got values and sometimes those values come to the fore and might result in the selective use of evidence.

INT: **As we've discussed there are various approaches to expert judgement, some of which broadly speaking rely on creating consensus, other's which don't bother with that but which try to test how effective the judgements are of experts on similar sorts of questions. Does what you've just been saying have a bearing on the kind of approaches that you could try to use in certain types of problems, maybe the more public and maybe the more controversial ones?**

RES: It's always an interesting process trying to procure evidence about a topic. First, you might want to know if there is an established viewpoint on the issue. Let's take climate change as an example. You could ask "is there a consensus around the evidence supporting manmade climate change" and the answer would be yes. It is a useful consensus as 98-99% of scientists agree with this statement. There might be disagreements around the role of the ocean as a carbon sink or the role of cloud cover in affecting warming. So, there might be disagreement on mechanisms, etc., but the consensus is useful because it can highlight to those asking the question that we have the evidence we need to act. I would always try to identify if there is a consensus but not to force one.

INT: **If you were to get a group of different experts who have been selected may be from different scientific schools of thought do you see, as a synthesiser of expert views, that some of those groups are giving you either more useful or more reliable evidence than other ones, or is that something that's a little bit too far away from a CSA's expertise to be able to make judgement on?**

RES: Well in the EU they constitute things called expert panels, for example, in the European Food Safety Authority (EFSA) and they will look at topics such as the safety of food additives and the expert panels peer review the

evidence available. The expert panels will also be asked to declare any potential conflicts of interest in order to highlight any potential for biased views. The management of these expert panels is important as I think it is useful to hear from those who may have biased views (e.g. a scientist working for a company that makes food additives in this case) but you might excuse them from any decision-making on the recommendations made. You could argue that we might all have some degree of bias but scrupulous transparency is helpful here.

INT: **Some people also use concepts of calibration and information of experts to assess the effectiveness of experts in making useful judgements of uncertainty. Calibration measures their ability to assess uncertainties, for example with 95% of outcomes contained within their 95% uncertainty bands, and information measures the relative narrowness of uncertainty bands. Do those concepts make sense or is there something that they're missing?**

RES: This approach could be useful in expert panels—where there is often a broad range of experts. You could do some analysis of how individual experts have performed with respect to how they approach uncertainty. I know this approach has been tried—although I do wonder how acceptable it is to panels of experts!

I am not sure this approach would have helped me with some of the divergent views I had to deal with. For example, in examining the impact of endocrine-disrupting chemicals we had large differences of views: some experts thought there could be catastrophic outcomes, while others thought the uncertainty wasn't significant. As CSA I needed to get them to agree on what the starting point was. This is the value of a CSA and helped to explain why their views diverge. It then enabled us to talk about the likelihood of the scenarios and how we mitigate the consequences.

However, I recognise that there can be different "personalities" of an expert. I've been in situations where there has been a vocal and sometimes antagonistic person that doesn't listen to others. I don't find that useful as part of an evidential framework. You need experts who are challenging and are willing to be challenged.

INT: **In Cooke's method these performance measures are used essentially to downweight experts who are less good (according to those measures) at assessing uncertainty. The resulting weighted average is called the rational consensus uncertainty estimate. Is that a useful summary of the expert evidence?**

RES: It could be. I always thought it was valuable to find where the weight of evidence lay, but it was also necessary to advise the government minister of the full spectrum of opinions, so they also appreciated if there was a range. If I could explain why a particular expert was underperforming then we could point this out and say that we might want to take this into account when placing weight on that view.

But in practice, other factors might contribute to what evidence a minister might use. They might give weight to an opinion which they liked to hear, and they often prefer to use uncertainty around the science to avoid the decision they don't like. It's very difficult to contradict this argument (the one referring to uncertainty), although it can be an abuse of the science and lead to questionable outcomes.

Experts help us by giving us a degree of confidence in a policy that delivers the desired outcome—this is where we need to get to. Policies aren't perfect as the evidence can change over time. For example, with EU biofuel policy—the incentive to grow crops for biofuels had an unintended consequence of land traditionally used for edible crops being taken out of that use. The real trick is to develop policies that are resilient and open to additional evidence that might become available with time.

INT: **The Precautionary Principle also influences the way that policy is developed from the scientific assessments. How has this affected the process?**

RES: When it was first introduced in the European Commission it was intended to allow us to take advantage of the developments of new technologies while minimising the risk from them. But it got reinterpreted over time as a brake on the use of new technologies. The challenge is to develop a policy that allows you to take advantage of new technology while taking account of the risks and to evolve that policy as time progresses and more evidence becomes available.

INT: **You've talked around a wide range of the kind of things that come up on the plate of a chief scientist. I don't know if this is possible but is there a percentage estimate you could give of the proportion of questions which come to the chief scientist which are potentially amenable to the use of these expert judgement methods, is that large or small or does the question not… is it too difficult to answer?**

RES: I think it is probably too hard to say because I think in some instances where you might seek consensus because you can see that there is perhaps very little spread of opinions and you are trying to make it simpler for the recipient of the advice. Then in other areas, you need to be very clear about the level of uncertainty so not seek consensus as that would be doing ministers a disservice if you tried to synthesise a consensus view for them because that could easily be undermined at a later stage and would undermine the minister's confidence in the evidence. You need to be able, to be honest about where there is significant uncertainty and then help a minister to both understand the extent, and the impact, of the uncertainty. In general, I feel that the use of expert judgement methods might have the greatest value in the step before a CSA gets involved and it is for the CSA to translate the output of the expert panels.

INT: **…and so there is also the issue of how grave the impact is?**

RES: I've mentioned the importance of the impact of uncertainty a lot and that is because sometimes the evidence has a high degree of uncertainty but it really doesn't matter because the impact, if you get it wrong, is quite low. So, for example, with endocrine-disrupting chemicals, you might have a consensus suggesting that particular uses represent a low risk but to some receptors (e.g. a developing foetus) the impact would be enormously high. Although the risk overall may be judged as low the potential harm could be very high. Ministers need to know this as it will likely impact the decisions they may make.

A Chief Scientific Adviser or a scientific advisor in many ways is a translator of evidence. That is a key part of the role because you should be able to understand the language of your peers, but you need to translate that into something meaningful for the person that is asking for your advice. There is always the danger that you lose some nuance or sophistication on the way in order to make it accessible.

I'm sure you get good Chief Scientific Advisers and not so good ones. Like everything in life, there will be people who will be particularly good at talking things through, but most of them particularly if they're independent, e.g. not part of the civil service, will be as truthful as they can be and will not fear to tell a minister something they really don't want to hear. It's much easier for a Chief Scientific Adviser to provide unwelcome evidence to a minister than it is for an official, because an official works for that person, they have a career, whereas for a Chief Scientific Adviser their main focus should be on working to be true to the evidence and not considering how it's going to be received.

I used to meet with all the UK Chief Scientific Advisers on a regular basis when I was CSA for Scotland. We did not discuss much expert judgement; we talked about what advice was being asked for and where evidence was likely to be sought. We also discussed how evidence could be brought to the fore when the policy was being developed. We didn't test ourselves in the same way or ask each other the questions that you're asking me now.

INT: **Yes, and there are two possible explanations, one is that these kind of structured expert judgement methods are just simply not known and the other explanation is that they are known a bit but they are either too difficult or too expensive to apply.**

RES: I think some of us did know about them but there is a broad spectrum of approaches to being a Chief Scientific Adviser. Some are incredibly collegiate and draw from a very wide pool of expertise. Others feel they can make expert judgements themselves without substantial input. In my view, the latter approach is a weaker one.

INT: **As a CSA there are probably times when you have had responded in the heat of a crisis—how do manage to respond at speed while maintaining a scientific perspective?**

RES: An example is when the Icelandic volcano Eyjafjallajökull erupted, I got a very anxious phone call from Alex Salmond who was First Minister of Scotland at the time. He said "a volcano's erupted in Iceland, volcanoes erupt all the time but there's a complete closure of air space in Scotland and that has big impacts for citizens trying to travel and for business. Why is this happening?" My reaction was to say I don't know but I'll find out because that is a perfectly reasonable question. I spoke to the NERC British Geological Survey who have expert volcanologists who understand about volcanic eruptions and they explained why the closure of airspace was necessary for this instance. I asked if theirs was the consensus view or would anyone disagree. Once I understood the information and that there was a high degree of confidence in it, I was able (within a couple of hours) to get back to the First Minister to explain what was happening and why. I didn't provide him with the detailed technical information but rather "modern jet engines are designed to burn fuel efficiently above their melting point. The reason they don't melt is that they are engineered with fine capillaries through the engine so when it's moving forward at speed, the air cools the engine. If you put glassy dust which is being expelled from Eyjafjallajökull into those capillaries it melts and blocks the capillaries after a period of time. The engine will melt and fall off the aeroplane and that's the reason that we've stopped aeroplanes flying in Scottish airspace" and he said, "OK that's fine"

My approach there was not to get a consensus view. It was to look at the rationale that people were using in order to ban flights in Scottish airspace. The plumes of dust from the volcano had been mapped. We knew that there would be a residence period for any plane within that dust and then work out what impact that would have on a modern jet engine. An initial precautionary approach was being adopted because potential consequences were severe. It was also accepted that restrictions might be relaxed as more evidence became available.

INT: **Yes, but of course there are other issues which are highly contested and more controversial and where there are ranges of opinion.**

RES: And even in the case of the volcanic eruption, propeller aircraft took air samples and this allowed experts to refine what the average concentration of dust particles was, the movement of the plume of dust was modelled and flight paths could be proposed that would avoid 95% of the glassy ash and calculations were that that might reduce air cooling if you did go through by a certain percentage but that it wouldn't melt. It would damage the engine…. and of course, the damage could be cumulative if you kept on flying the same engines through that over a period of time. What is important is to be able to make evidence-based decisions quickly as ministers need to act and to communicate about the issue.

INT: **Its clearly a challenging role, so is there a course of training for a chief scientist?**

RES: No, I suspect the training is being a scientist because all of us do it, you do it whether you're in big collaborative projects or you're in peer review panels where you're having to discuss evidence and you're having to weigh up the different scenarios… your life as a research scientist probably is the training to allow you to facilitate the prioritisation or use of evidence in a case like that particularly quickly. You've got time to be much more cerebral as a CSA and it's a very small proportion of a scientific advisor's role to respond to an emergency like that. I think it only happened to me a couple of times in the Scottish Government and only once at the European Commission.