

Science, Innovation and Technology Committee

Oral evidence: The science and risks of nuclear monitoring and enrichment, HC 1134

Wednesday 25 June 2025

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Members present: Dame Chi Onwurah (Chair); Emily Darlington; Dr Allison Gardner; Kit Malthouse; Dr Lauren Sullivan; and Adam Thompson.

Questions 1 to 109

Witnesses

[I](#): Dr Alexander K. Bollfrass, Head of Strategy, Technology and Arms Control, International Institute for Strategic Studies; Professor Sir Robin Grimes, Professor of Materials Physics, Imperial College London; and Professor Tom Scott, Professor in Materials, University of Bristol.

[II](#): Mark Foy, Chief Executive and Chief Nuclear Inspector, UK Office for Nuclear Regulation; and Karine Herviou, Deputy Director General and Head of the Department of Nuclear Safety and Security, International Atomic Energy Agency.

Examination of witnesses

Witnesses: Dr Alexander K. Bollfrass, Professor Sir Robin Grimes and Professor Tom Scott.

Q1 Chair: Welcome to this morning's special sitting of the Science, Innovation and Technology Committee, where we are conducting an inquiry into the science and risks of nuclear monitoring and enrichment. Our aim is to understand the science of enrichment, the science of detection and the science of understanding the impact around the strikes.

We are pleased to welcome our first panel, and we will kick off straight away. I will ask you to introduce yourselves as you answer my first question. We know that Iran has been enriching uranium and we know that that can be enriched to all kinds of different levels, which have different implications. Can you take us through the science of enriching uranium and how and where the Iranians are doing it? I ask Sir Robin Grimes to start.

Professor Grimes: Thank you very much indeed for having us here today. My name is Robin Grimes, a professor in the materials department at Imperial College.

The idea of enrichment is that you take natural uranium, which is 0.7% of a particular isotope—uranium-235—and you change the relative content up so that a greater proportion of the uranium isotopes are present. You do that to fuel for reactors, which is about 5%; for special reactors, which is about 20%; and then you go on to what is usually thought of as weapons-grade materials, which is at 90%.

There are a number of different technologies, but centrifuges are the usual way of doing it. They are very energy-intensive—that is an important aspect of this. They are columns. They vary quite a lot, but they are a few metres tall, about 30 cm or 40 cm in diameter and they spin at colossal rates of about 50,000 rpm.

Q2 Chair: What are they spinning?

Professor Grimes: Inside them they are spinning uranium hexafluoride. The reason for that is that the uranium atoms are in molecules that are in a gas. By spinning them very fast, the heavier isotope—the uranium-238 UF_6 molecule—goes to the outside and the uranium-235 UF_6 molecules tend to stay towards the centre, due to the difference in mass. But, as you know, the mass difference is very small; that is why you have to spin them at such a colossal rate.

You then take that gas off and feed it into the next centrifuge, and the next one, and the next one, and the next one. There are many hundreds of these centrifuges, all linked together with an incredible network of pipes. They sit on bearings that are very sensitive indeed—sensitive to shocks, in particular.

Q3 Chair: That will be very relevant; we will come on to that. Of the mined uranium ore, 0.7% is the isotope that you want—is that right?



Professor Grimes: That is right: a very small percentage.

Q4 **Chair:** When you are spinning the uranium, are you looking for the heavier or the lighter isotope?

Professor Grimes: You separate the two isotopes in that manner, but only by a small amount in each spinning centrifuge. You then go from one centrifuge to another.

There is one other important issue to bear in mind. When you go from 0.7% to 5%, although that does not sound like a big difference you actually do an awful lot of the work necessary to get up to the weapons-grade material. By the time you have got to 60%, which is what the Iranians claim they have, you have done over 90% of the work necessary to get to 90% enrichment. You have done all the hard miles already.

Q5 **Chair:** That is very relevant. Professor Tom Scott, would you like to add something?

Professor Scott: Absolutely. I am Professor Tom Scott from the University of Bristol; I am a professor of nuclear materials and devices.

To build on what Robin said, one important point is that the nuclear fuels that we use in power stations have an enrichment of typically between 3% and 5% uranium-235. As Robin said, 20% enrichment would be for a research reactor. There is quite a big difference between that 20% and the 90% required for nuclear weapon material, so there is very clear ground between those two levels. A 60% enrichment level is well beyond the level that you would need for a fuel.

Q6 **Chair:** That is very important. Dr Alexander Bollfrass, can you introduce yourself and make any additional comments that you wish to make?

Dr Bollfrass: Thank you for having me, and good morning everyone. I am Alex Bollfrass, head of strategy, arms control and technology at the IISS office in Berlin. The only point I would like to add is that the history of the Iranian programme began with a design for a centrifuge taken from the Urenco facility in the Netherlands—Urenco is a European enrichment corporation. That design was taken to Pakistan and then later sold on to the Iranians.

The entire programme that the Iranians have developed has been based on that particular original design, which was actually discarded by Urenco as not being especially efficient, so the main accomplishment of the Iranians was to take a non-working design and build several generations out of it to make it more useful. At the moment, we are most concerned about the sixth generation of the centrifuge, which is much more powerful than the previous generations, and of which the Iranians have quite a bit of installed capacity. They have also introduced designs for another three generations, but those have not been used at a large scale yet.

Dr Gardner: That answer links to a question that I wish to raise, based on what you were saying, Sir Robin. Very technical, specific equipment is being used; the bearings that you described sound like very high-level



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engineering. Are they making that equipment in the country, near the facilities that are bombed, or is it in a supply chain that we can trace? I am sure that you cannot just open the Philip Harris catalogue and choose this equipment.

You say that they are making it themselves based on older centrifuges. Where do they get the bearings from? Are they making them in Iran or are they getting them from somewhere else?

Professor Grimes: I spent time in Tehran in 2019 as part of the JCPOA. I looked after the plutonium part of the programme.

Q7 **Chair:** Could you just say what the JCPOA is?

Professor Grimes: Sorry—the Iran deal, which the UK took over when the Americans pulled out. I have to say that I was very impressed with the quality of the engineering that the Iranians had. I also visited their nuclear university; again, I was very impressed with their intellectual and engineering capabilities. They clearly have technologies from numbers of different countries. They have been very good at getting supply chains set up from countries such as Pakistan and so forth, but we should not underestimate their capability to carry out quite sophisticated engineering and science understanding themselves.

Q8 **Adam Thompson:** Robin, I want to pick up the point you made about Iran's position. They stated that they have got to 60%, but you both noted that getting to 60% maybe requires 90% of the work. How confident are we that they have not actually done the final 10% to reach the 90% weapons-grade uranium?

Professor Grimes: Alexander may know that better than I do. I think it is very difficult indeed to know that for certain. The fact that they have told us that they have a considerable amount at 60% is interesting. I am not sure I would know, to be perfectly honest. Tom, do you have any thoughts?

Professor Scott: I agree with Robin. It would be speculation about exactly how far, if they have gone beyond the 60%, and about how much material they have. It is also worth noting that the generally agreed view on enrichment is that you are looking at a level of 90%. You do not have to go quite as far as that, but you need a lot more material. There is a lot of speculation, and what is required is more definitive information. That would be great, but obviously it is very hard to get hold of that information.

Q9 **Adam Thompson:** It would not be right to speculate, of course, but do you want to comment on that, Alex?

Dr Bollfrass: The last official report that we have from the International Atomic Energy Agency on the Iranian programme is from May; in that, the IAEA has full view of the entire uranium stockpile that it has been aware of over the last few years. It reports that nothing has been enriched higher than 60%. Of course, the question is whether there are any parallel

facilities in which the Iranians have diverted some of their uranium stockpiles. That is something we just do not know at the moment.

- Q10 **Chair:** By “parallel facilities”, do you mean facilities in addition to the one in the mountain at Fordow, or do you mean facilities that are there but not inspected by the IAEA?

Dr Bollfrass: That is right. About two or three days before the Israeli strikes began, the Iranians had notified the International Atomic Energy Agency that they had a new facility that they had not yet told the agency about, and they were in the process of notifying them about it. It is unclear whether anyone—the Americans, the Israelis—knows where this new facility is and what kind of equipment or materials would be in place there.

- Q11 **Adam Thompson:** One more from me on this point. Do we have any means of remotely detecting what sort of stockpile they have in Iran, or is it purely based on the knowledge they have given to us in the conversations that have been had over the past few days?

Professor Scott: I should add one piece of historical information, which you can get from the World Nuclear Association website. We have talked about 60% and 90%. The “Little Boy” device dropped on Hiroshima at the end of world war two was 64 kg of uranium enriched to 80%. I think that gives you some idea that you do not have to reach or exceed 90%—you just need a lot more material.

Auditing the amount of material is partly the role of the IAEA; I understand that you will hear from them in your next session, so I will leave it to them to comment. They have an online monitoring system, which is a special type of gamma spectrometer detector that measures gamma in a pipeline as material flows through it, so they can measure the enrichment level. That is how they have gathered some of their information. Typically, they are looking at enrichment levels of about 3.6%, but with a spectrometer like that you can evidence and quantify how far above that you have gone.

- Q12 **Adam Thompson:** That is really interesting, Tom. Would you need a sample of the material for that spectrometer?

Professor Scott: My understanding is that it samples material as it goes through. It harvests some of the radiation given off by the material, which gives a specific fingerprint that you can use to differentiate between uranium-238 and uranium-235.

- Q13 **Adam Thompson:** At what sort of distance from the location of the material are we talking about?

Professor Scott: My understanding is that the sensor is located inside the facilities, and there may be more than one. It is an online monitoring system overseen by the IAEA.

- Q14 **Chair:** But it has to be there with the agreement of the Iranians.

Professor Scott: Yes.



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Q15 **Chair:** Can you clarify for me which uranium isotope is being enriched?

Professor Scott: Uranium-235, which is the light isotope. The heavier one is uranium-238, which isn't of any use for atomic applications—for generating power.

Q16 **Chair:** It isn't of any use. So uranium-235 is one being enriched for both civil and military means.

Professor Scott: Yes, that's correct.

Q17 **Kit Malthouse:** Can I take you back to the manufacturing process, from a technical point of view? When the uranium is mined, it comes as a solid ore; in what form does it enter the centrifuge?

Professor Grimes: You mine and then you process it to increase the content of uranium and discard the other bits of the rock, as it were.

Kit Malthouse: When you say "process", do you mean that you heat or crush it, for example?

Professor Scott: You dig it out of the ground and you have uranium ore minerals mixed with other minerals. The first thing you typically do is to separate, as best you can, using different physical and chemical processes, the uranium ore from the other minerals. In that processing you also remove all the other elemental contaminants so that, going forwards towards enrichment, you have a very pure uranium product. It is typically an oxide—uranium bonded with oxygen.

Kit Malthouse: So it is a solid at this point.

Professor Scott: It is a solid, yes. It is sold on the international markets as a substance called yellowcake—it is bright yellow.

Kit Malthouse: Can anyone buy it?

Professor Scott: Not anyone can buy it. Subsequently, that material has to go through a fluorination process in which, essentially, the oxygen bonded with the uranium is swapped for fluorine. Typically, you increase the amount of fluorine until you have six fluorine atoms bonded to every uranium atom. That is then a gaseous compound that is used in the centrifuges. It is one of the only gases that you can form with uranium; the centrifugation process is based on using a gas, so that is why that substance is used.

It is chemically very pure, but because it is fluorinated, if hexafluoride were to mix with water vapour in the air, or with water, it would very quickly degrade and form a very, very strong acid called hydrofluoric acid, which is one of the strongest acids we know. If there were ever an accident in a plant that contained a large amount of uranium hexafluoride, and there was also water present—you may have water because of something like a fire-suppression system—you would likely have a lot of damage, because it would be a very significant chemical incident.

Q18 **Kit Malthouse:** That is part of the reason why I am asking; I am going to



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come to the risks in a minute.

So this stuff is spinning in these dozens of centrifuges in gaseous form—it is a gas that is inside—and you have indicated, Sir Robin, that it would have to be quite a large facility for it to be effective.

Professor Grimes: Yes.

Kit Malthouse: With dozens and dozens of centrifuges.

Professor Grimes: Hundreds.

Kit Malthouse: Could you give us a sense of scale? Are we talking about Wembley stadium? How big would the facility need to be in a single place?

Professor Grimes: It would depend on how much throughput you expect to make. Wembley stadium would be a quite a large facility; that would be similar to Capenhurst in the UK. You do not necessarily have to have something quite that large, but it is certainly the size of many, many tennis courts, even for the smallest facility. So it is big.

Kit Malthouse: So quite hard to hide.

Professor Grimes: There is another point to this: the energy used to spin all these things up in that way means that there is a big energy signature. I think this was true in North Korea, wasn't it? Those facilities were spotted because of the energy consumption.

Q19 **Kit Malthouse:** A dedicated power plant would be required. And that adds to the size of the facility if you have it proximate, I guess.

Professor Grimes: Yes, or you have a lot of lines coming in.

Kit Malthouse: And big sub-stations and all the rest of it.

Professor Grimes: That is how you would spot it.

Q20 **Kit Malthouse:** I don't mean to be flippant, but this is not something that is casually done.

Professor Grimes: No.

Q21 **Kit Malthouse:** This is many years of engineering, construction, planning and all the rest of it.

Professor Grimes: Absolutely. And your Chair is a chemical engineer, if I remember.

Chair: I am an electrical engineer, from Imperial as well.

Q22 **Kit Malthouse:** So we get to the end and this stuff is still a gas. How does it then become a solid? Does it need to be a solid?

Professor Grimes: There are then a number of ways, but as Tom was talking about, you introduce steam into the system—this is how we do it in the UK—and you create that reaction. You create that hydrofluoric acid, you recycle that and you end up with uranium oxides. There are numbers



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of these uranium oxides. You take those and form them into a powder, and what we do is take the powder and turn it into pellets, which are then the fuel that goes into the nuclear reactors.

- Q23 **Kit Malthouse:** One of the concerns about what has happened in Iran is that they removed some of the material and stored it. Would they remove it in pellet form, or gas form?

Professor Grimes: As Tom was explaining, uranium hexafluoride is a gas, but when you reduce the temperature to room temperature, it becomes a waxy solid. It is in these big steel containers, which interestingly, would be about the size of the area just here in front of us. These are big, steel containers, which have lining to prevent the interaction of the uranium hexafluoride with the steel, and those are then moved around. That is how the enrichment plant then delivers the uranium hexafluoride to that place where it interacts with the steam and so forth.

- Q24 **Kit Malthouse:** At that point, how stable is the material?

Professor Grimes: As long as there is no rupture of the vessel that it is being contained in, it is completely stable.

- Q25 **Dr Lauren Sullivan:** In these large containers, how many kilograms or grams-worth of uranium is there?

Professor Scott: First of all, you have to remember that uranium is very dense, so any uranium compound tends to be very heavy for any given volume. If you take a uranium oxide particulate, its density is about 10g per cc, which is about 25% denser than steel, so it tends to be very heavy. For the quantities, it depends on the type of container that you are using. In the UK, Urenco has specifically very well designed containers for holding and moving the material around. You are talking hundreds of kilograms, typically—maybe slightly above that.

Professor Grimes: Of course, that is at 5% or 4% enrichment. When you go to higher levels of enrichment, for criticality control you would probably go for smaller containers, I would think. Is that right?

Professor Scott: Yes, you would have to.

- Q26 **Kit Malthouse:** It would be very heavy otherwise, from a practical point of view.

Professor Grimes: No—it is that you don't want that many uranium-235 atoms.

Professor Scott: You risk something called a critical mass where you have too much uranium-235.

- Q27 **Kit Malthouse:** Then from a stability point of view, quantity matters, does it?

Professor Grimes: It does. I think Alexander might know.



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Kit Malthouse: Alexander, if you want to intervene, please raise your hand or send a signal.

Dr Bollfrass: I just emphasise that I am not an engineer or a physicist here. One thing I do know is that the Iranians do tend to move their uranium hexafluoride in much smaller containers than we would do in the west. That is why there has been a lot of speculation about at what point over the last week the Iranians might have been moving the uranium around in order to protect it from the strikes.

Q28 **Kit Malthouse:** I have two further questions. Obviously, I guess there are two elements of the technology: one is the enrichment, and the other is getting it to explode. Assuming that the Iranians can get to 80% or 90%, what level of expertise is then needed for it to detonate? Is that a whole other world of engineering and pain that they may not have the capability for?

Professor Grimes: That is a really important question. There are two ways of making nuclear weapons. One is based on plutonium, and one is based on uranium. The Iranians have clearly gone down the route of uranium. The reason is that it is much easier to make a uranium-235-based weapon undergo a nuclear explosion. You basically have a large lump that is sub-critical, and another lump that is sub-critical, and they are shaped so that you can fire one into another.

The physics of how that occurs means that that simple explosion is enough to get you a critical mass—a mass over the key amount. That depends on the enrichment levels, but it is very simple. It is a gun-like assembly. When the Americans dropped their weapon on Hiroshima, they just did it—it was a first-off. They did not need to practise or have another weapon to see whether it worked, because the physics is so straightforward.

Q29 **Kit Malthouse:** So detonation is not a hard thing to achieve, from an engineering point of view?

Professor Grimes: Not at all.

Q30 **Kit Malthouse:** Out of interest, why would people choose plutonium over uranium?

Professor Grimes: That is a difficult question. The reason you would use a plutonium weapon, if you had the facilities to make it work—it is much harder to make it work—is because you can use it to do other parts of a nuclear weapon as well. I will leave it at that, if that is okay.

Q31 **Dr Gardner:** I have two questions. One is quite a key question, but I also have a developing interest in how we build nuclear reactors, particularly with fuel cell coatings and fuel coatings. You mentioned that it is put into the container and that it has a coating to prevent it reacting with the steel. What is that coating?

Professor Grimes: I am not sure I know the answer. I can get back to you on that. I think your next panel will know the answer to that.



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Professor Scott: In essence, it is a coating material, and there would be a number of candidates you could choose. It is just non-reactive with the material that is inside.

Q32 **Dr Gardner:** I will ask the next panel. It is just personal interest.

The second question is quite important, and it goes back to you outlining the use of the spectrophotometer to understand the purity and what additional minerals are there. This comes back to detection from an international point of view. Once you have a release of the radiation, is there a way of us detecting that via similar technologies internationally? Also, via that, even though through the purification process, can we look at the trace elements in there and can we detect the original source of the uranium?

Professor Scott: That is a very good question. First of all, yes, there is a monitoring network in almost all countries. The UK has a monitoring network of spectrometers so, if anything blows in from another country, we can detect it very quickly. Countries all around the world have a similar network, and you can feed information from your network into the International Atomic Energy Authority monitoring system, so there is a global awareness. You can access that kind of information through the internet now, in fact.

Q33 **Dr Gardner:** If, when the bombing has happened on these sites, there is any radiation leakage, can we analyse that and understand, first, whether there is radiation leakage, and secondly, what type of uranium it is and whether there is trace elements, so we can detect the source of that uranium?

Professor Scott: It goes back to my point that the uranium compounds—solid compounds—are very dense. They do not travel very far at all in air, even after an explosion. Experimental data tells us that as well. That is quite useful in understanding that, hitting these facilities, there would be expectation that even in surface facilities, the material would not travel very far because it simply so heavy. If the facility is underground, although that is obviously to protect it from kinetic strikes, being underground is actually quite good containment as well.

The IAEA has not reported any release of radioactivity—I personally would not have expected it either—but, if we were able to get samples of material, from a forensic standpoint, we have very good forensic technologies in the UK and internationally. The Atomic Weapons Establishment runs our UK capability for nuclear forensics and, yes, we would be able to analyse material and look for specific fingerprints, whether that is the isotope ratio, the chemical form of the material or the trace elements.

Q34 **Dr Gardner:** Related to that, there must be very few places on Earth where you can mine this uranium. Where can you mine it?

Professor Scott: Uranium is actually more common than you would think. Most of the uranium in the world is currently mined in Canada and



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Australia, and Kazakhstan also has a lot of uranium, but there are untapped uranium reserves around much of the developing world.

Chair: Does Iran have uranium reserves?

Professor Grimes: It has a lot of thorium, doesn't it? But I don't think it has a lot of uranium.

Chair: Thank you. We were talking about the risks—the impacts—of a strike, and that you would not expect the uranium isotopes to be able to be detected because they are so heavy—wasn't that what you were saying?

Professor Scott: We would not expect them to be able to escape because they are so heavy.

Q35 **Chair:** My understanding is that the complex at Fordow is 400 metres underground, and that the bombs that the US military used could penetrate 60 metres, so I don't think there was an expectation that the nuclear material would be directly hit—or was there?

Professor Grimes: These facilities, as we have described them, with these large numbers of high-spinning devices, are very sensitive; the bearings on which they sit are very sensitive. If you were able to disrupt those as they were moving, you would do extraordinarily large amounts of damage, even if you only went 60 metres and then exploded, because of the sort of earthquake-like effect.

Having said that, of course, Iran is subject to earthquakes naturally, so it will have built its facility to be able to withstand those sorts of vibrations. Nevertheless, I think it is highly likely—although, again, we are careful not to speculate—that it could well have done very considerable damage none the less.

Going back to the IAEA question—the detection question—I think we ought to differentiate here between the uranium-based contamination that would emanate if those facilities had been badly damaged and the detection of radiation as a consequence of a nuclear reactor being damaged, or were there to be an illicit nuclear weapons test by a nation. In those cases, we are looking for quite different isotopes—we are looking for fission products—and we would not have expected there to have been a release of fission products as a consequence of the Fordow explosions and so forth.

Professor Scott: Simply because they would not have been there. They were working with a very clean chemical product there. Uranium is obviously radioactive, but primarily it is an alpha-decayer, and alpha radiation is extremely short range—an alpha particle travelling through air will typically go up to a maximum of about a millimetre. To detect it from a distance is extremely difficult. You get some soft gammas that also come off from decay-chain daughters, but, again, you need to be very, very close to be able to pick it up. So there is no chance that you could pick it up from large distances.



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Q36 **Chair:** So what you are saying is that the absence of any detected radiation is not an indication of the success or failure of the strike.

Professor Grimes: That is fair to say.

Professor Scott: Yes, I think that is correct to say. What Robin was alluding to was that, with nuclear power plants, when the fuel has been in the reactor and the uranium-235 has been fissioning, you then have a build-up of fission products, which are very highly unstable and radioactive. That is the dangerous part about nuclear fuel. With Chernobyl and Fukushima, it was about the release of those fission-product isotopes, which can be released as gases when the temperatures are very high. That was what monitoring networks around the world were able to detect; they were detecting a radioactive gas. That is not the case here, because we do not have fission products.

Dr Bollfrass: I want to make a quick note that there has been concern that the Bushehr nuclear power plant, which is a nuclear power reactor on the Gulf, would be targeted by the Israelis. A lot of the Gulf countries have been quite concerned, but it has long been Israeli policy—for example, when they struck reactors under construction in Iraq in the '80s and in Syria in 2007—not to hit operating reactors. That is a big facility where the radiation danger would be quite severe if struck.

Chair: Thank you; that is very helpful.

Q37 **Adam Thompson:** I have a question on the enrichment process—correct me if I am wrong in my thought process. If the raw material that you are pulling out of the ground is about 0.7% uranium-235 and the rest is uranium-238, and you are moving up to 60% or 90% or whatever in the enrichment process, you are going to produce a large amount of uranium-238 as a waste product. I have two questions: what happens to that uranium-238, and do we have any capability to monitor that remotely to make inferences about how much uranium-235 has been produced?

Professor Scott: Uranium-238 does not really have any industrial uses. It has some uses in defence—certain types of munitions contain a uranium-titanium alloy, which is good for hitting tanks—but it has quite limited use. The majority of uranium-238 that is produced as tails from different facilities around the world does not really have a use. Typically, it is stored in specialist storage tanks, often as hexafluoride, as Robin has described. You cannot detect its radioactivity from a stand-off distance, because it is an alpha-emitting substance. Depending on where and how it is stored, it may have a footprint that could be observable from a distance, because you are correct that there would be a lot more uranium-238 tails produced than enriched material.

Professor Grimes: Yes, if you were to start off with roughly 1,000 kg of uranium—of course, it is more than 1,000 kg because it is in an oxide form, but let us say roughly 1,000 kg—you would end up with, I think, something like 120 kg of enriched nuclear fuel material and about 2 kg or 3 kg of highly enriched uranium at the 90% level.



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Q38 **Adam Thompson:** And then the rest—a large amount—is waste.

Professor Grimes: The rest is waste, although you can come back and try to get some more of that uranium-235. That is actually done.

Q39 **Adam Thompson:** But at some point it goes into some storage facility or a facility the size of the one that we are talking about in Iran. How much volume of “waste” uranium-238 are we talking about being in storage?

Professor Scott: I think that would be for the IAEA to comment on. As part of IAEA reporting processes for most countries, you have to provide a stock check of the materials that you hold.

Professor Grimes: I think it is fair to say that it would be thousands of kilograms.

Q40 **Emily Darlington:** I am not asking you to speculate on how much damage was or was not done to the underground facility, but as you spoke about, any kind of breach of the material in the centrifuge creates quite a bad acid if it is exposed to water, or it could be released in a gaseous form, which would have a number of effects. How worried should we all be about the environmental impact of that seeping out into the ground, particularly as an acid or in a gaseous form? What kind of environmental impact would that have?

Professor Scott: First, it is important to state that any environmental impact would be extremely local, so there would not be any widespread contamination issues. Uranium is mildly toxic. It is about as toxic as lead, so it does not pose an extreme immediate risk unless it is in very large quantities.

The routes for human harm would be either by inhalation of a fine powder or gas, or by ingestion, which would be slightly slower. The reason is that, if the uranium gets inside your body and has direct contact with cell surfaces, the alpha radiation that it gives off is physically damaging to those cells. It can cause cell death and potentially mutations that might manifest further down the line in cancers.

Q41 **Emily Darlington:** Then with that extreme localisation, we are not talking about something like Chernobyl, where there was an extreme environmental impact.

Professor Scott: No, not at all.

Q42 **Emily Darlington:** Let's say it turns into the acid and gets into the soil; that is again likely to have quite a limited impact on the local environment.

Professor Scott: Absolutely, especially because some of the facilities are extremely remote. You need not only a source, but a pathway to the receptor, which in our case would be the humans. If there is no pathway for humans to become affected, you do not have a problem.

Q43 **Emily Darlington:** Is that risk increased if it is being transported? If they are moving the material around and it gets hit, is that risk of environmental impact increased?



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Professor Scott: I would say not substantially. Obviously, it is not underground, but there are specially designed and engineered casements for it. If there is a breach, again, contamination will be extremely localised.

Q44 **Emily Darlington:** But presumably strikes would be able to penetrate those containers; some of the strikes are quite powerful.

Professor Grimes: I think that is theoretically possible.

Emily Darlington: I am only asking for the theoretical.

Professor Grimes: But again, because of all the things Tom has talked about, the contamination would be relatively local and, if they had the facilities, it would be possible to clean up the vast majority of that.

Q45 **Emily Darlington:** These questions are all theoretical, because we only have the information that we have; I am not asking you to speculate on what has happened, but trying to understand the risk. My final question is this: because uranium, as you said, is quite simple to detonate, even if it is not fully enriched—let's say not even at 60%—is there a risk of detonation if it is hit, or does it need to be uranium hitting uranium, rather than another device hitting it, to cause an explosion?

Professor Grimes: It would be possible to carry out work to assess that risk. Without having that data it is hard to be definitive, but what I would expect is that, if the uranium hexafluoride from a single container was to leak out, it would then react into the environment and produce uranium oxides. Usually, for a weapon, you would use metal; here you have diluted it, and the more it is diluted through those chemical reactions, the greater the mass you would need to get to some sort of criticality. I would be very, very surprised if it would lead to some form of nuclear excursion.

Q46 **Emily Darlington:** So an explosion generated by a strike is not enough to create a secondary reaction with the material.

Professor Grimes: Again, I look to my colleagues to be definitive—or perhaps more definitive—on this. I would be very, very surprised indeed, but the calculations ought to be done to check.

Professor Scott: A strike such as you are suggesting is likely to disperse the material as opposed to doing the opposite, which is to increase the density of the material—in which case, it is driving it in the wrong direction.

Chair: We are coming to the end of the time for this panel—it has been fascinating. I know Lauren has a question about scientists' involvement; Allison, did you want to come in first?

Q47 **Dr Gardner:** Given what you have said about detecting the source and that they can engineer the components they need to make these facilities, and about it being quite hard to detect any radiation from them, what proof do we have that these facilities are where they are, and that they exist? I am asking from a technological point of view, within the remit of this inquiry.



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Professor Scott: In terms of what Alexander has explained, any nation state that is working with nuclear facilities and nuclear materials will disclose the facilities to the IAEA. The IAEA has a register of facilities. As Alexander was explaining, the Iranians were about to announce that they have a new facility. The facilities that were struck were recognised and monitored by the IAEA.

Dr Gardner: Thank you.

- Q48 **Chair:** Just to be clear, I think you were saying in your responses to the questions from Emily, in particular, that the risks of this strike to anyone else outside Iran, and even to most people within Iran, are minimal.

Professor Scott: Correct.

Chair: That is really helpful.

- Q49 **Dr Sullivan:** Obviously, a number of scientists working in this area have been targeted and killed. How much do you think that will have an impact on the work that is being done and on their aims? In essence, how can we keep scientists safe?

Chair: Dr Bollfrass, I think you wanted to respond to that.

Dr Bollfrass: From the officially announced names of the scientists who have been killed over the last week, it seems that about half of them were affiliated with the uranium enrichment side of the programme. There, the Iranian programme is deep in expertise, so I don't think it will have much of an effect on their ability to reconstitute the programme.

The other half, roughly speaking, are those affiliated with the SPND, which is the Farsi acronym for the Organisation of Defensive Innovation and Research. That is the programme that has been involved on the weaponisation side of the Iranian programme—it is those who would be taking the highly enriched uranium and turning it into a deliverable warhead. That is a much smaller cohort of people because of the extreme secrecy surrounding the programme, so I imagine the effect there has been much more pronounced in constraining the Iranian ability to develop a warhead.

- Q50 **Chair:** Thank you. You mentioned the announcement of the scientists who have been killed in the Israeli attacks. Is it possible that the US attack on the facility has led to further scientists and technicians being killed in the facility, either through the reactions that we have talked about or through direct damage?

Dr Bollfrass: It is certainly conceivable, although it has been reported that the United States gave advance warning to the Iranians, so presumably they would have evacuated at least their most prized and capable personnel.

Chair: We are coming to the end of this panel, but there are a couple of points that we have not covered.



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Q51 Kit Malthouse: I just want to ask a question of Dr Bollfrass. We have obviously all seen the news this morning of the alleged intelligence leak about the programme being set back by only a few months. We have talked a bit about the possible damage to the engineering from the bomb, and about the scientists and the impact that might have. Feel free to say that you do not want to comment, but does it feel to you that the intelligence leak that it has set them back by only a few months is credible, or do you think it has set them back by years?

Dr Bollfrass: There are a couple of different ways of doing the battle damage assessment. The best way, of course, is satellite imagery, but that works much better for the above-ground facilities that have been struck. There is still a lot of mystery around what the underground facilities look like. One of the ways of figuring out what has happened is through signals intelligence, which the US has plenty of. That is effectively about listening to what the Iranians are talking about internally.

Rumour has it that the Defence Intelligence Agency assessment that has been leaked is a combination of the satellite imagery and the larger picture based on conversations among Iranians themselves. Of course, the question is how much the Iranians who are overheard talking know about the actual state of the facility. It is certainly a credible report, but it is not the final word on the subject.

Q52 Kit Malthouse: If the centrifuge was completely destroyed and they decided to start from scratch, how long do you estimate it would take for them to get back to the same level of capability?

Professor Scott: If you started from scratch, it is a very substantial and expensive endeavour that would take many years.

Q53 Kit Malthouse: So the range of possibility is from many years to a few months, but we do not actually know at the moment.

Professor Grimes: That is fair to say, yes.

Q54 Chair: We have talked a lot about the Fordow facility. We know there are other facilities. Is it possible that they have been extensively damaged as well? You mentioned that the Iranians had notified a new facility to the IAEA. Dr Bollfrass, is it possible that there are other facilities that are undamaged?

Dr Bollfrass: That is definitely a possibility. As far as I know, no one knows where this new facility that the Iranians were about to announce to the IAEA would have been. It could, of course, be that they have additional facilities that they had no intention of telling the IAEA about.

The other two sites that are worth looking at, which have been hit and were integral to the nuclear programme, are at Natanz and Isfahan. Both of those have extensive underground facilities associated with them. There, it is the same mystery as with Fordow. We know that quite a bit was destroyed on the ground, but we are still for waiting for word on what the impact was below ground.



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Q55 **Chair:** Sir Robin, you spoke about energy consumption being a marker for a facility. Is that still the case if the facility is deep underground?

Professor Grimes: Absolutely. It would be very hard to put a big power plant underground. Presumably, they are using oil to get that energy, or they would have very large solar arrays or something like that. Either way, you are going to be able to see them.

Q56 **Chair:** So we should be able to identify any new facility.

Professor Grimes: I think that is right. There is intelligence gathering on the ground as well, which has clearly been occurring. I think it would be very difficult for them to keep a substantial facility hidden—small research facilities perhaps, but a very substantial facility where you can do a lot of enrichment would stand out very quickly as soon as it was turned on. Tom, would you agree with that?

Professor Scott: I would agree.

Chair: Thank you so much. I think we are all much better informed on the process of enrichment.

Kit Malthouse: To be honest with you, I am relieved. It was effectively a low-risk strike.

Q57 **Dr Gardner:** Can you tell the difference between 3.5% and 90% enrichment facilities? What were they announcing to the IAEA—reactor-grade or weapons grade development?

Emily Darlington: They are not allowed to do weapons grade.

Dr Gardner: I am a bit confused.

Professor Grimes: You could use the same facilities to go from 0.7% to 5% that you can go from 5% to 90%. It is exactly the same technology.

Chair: Thank you so very much. We appreciate your contribution.

Examination of witnesses

Witnesses: Karine Herviou and Mark Foy.

Q58 **Chair:** Welcome the second panel in the Science, Innovation and Technology Committee's inquiry into the science of nuclear enrichment and the impact of the recent strikes. I am pleased to welcome our two guests this morning. I will ask you each to introduce yourselves as you respond to this initial question. Can you tell me about your work in monitoring the enrichment of nuclear material in Iran and elsewhere, and the work of ensuring that the risks from nuclear material are understood?

Karine Herviou: Good morning. I am Mrs Herviou, and I am deputy director general of the International Atomic Energy Agency and head of the Department of Nuclear Safety and Security.



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The IAEA has been monitoring the situation in Iran for several years in the frame of the non-proliferation treaty. That means that we have inspectors specialising in safeguards who inspect Iranian installations to verify the inventory of nuclear materials that Iran has declared.

In the frame of the armed conflict, we also have an Incident and Emergency Centre that is monitoring the situation in enrichment and conversion sites. We assess the possible consequences, and we have been having some exchanges with the Iranian regulatory authority, which can report on the consequence of these strikes.

Of course, there are also other risks in the Iranian state due to possible strikes on other nuclear installations. We also look at those and try to monitor the situation, mainly on the basis of monitoring networks that are shared by surrounding Gulf region countries so we can check that there is no increase in the residual level that could be due to an accident in a reactor—not in the conversion and enrichment plant, but if there was an accident or a strike on a research reactor or a nuclear power plant, there would be a release, and that could be detected through monitoring those gamma rate measurements in the Gulf region countries.

Q59 **Chair:** Do you have people on the ground in Iran?

Karine Herviou: There are still safeguards inspectors in Iran. They were in the Iranian nuclear sites that were struck a few days before 13 June. They stayed in Iran and they are ready to go back to the installation to verify the inventories of nuclear materials.

Q60 **Chair:** When will they be doing that?

Karine Herviou: We are waiting for a discussion with the Iranian state to have the ability to go back to that installation.

Q61 **Chair:** Is that to the Fordow installation?

Karine Herviou: It is to the Fordow, Natanz, Isfahan and Arak sites.

Q62 **Chair:** Thank you. Mark Foy?

Mark Foy: Good morning. I am Mark Foy, the chief executive and chief nuclear inspector for the United Kingdom's Office for Nuclear Regulation, the UK's independent regulator for nuclear security, nuclear safeguards and nuclear safety. We have around 450 highly specialised, qualified experts within the regulatory body who can look at the safety and security standards that have been established in the facilities within the United Kingdom. We look at the various justifications for that safe operation.

We also work internationally with the International Atomic Energy Agency. The IAEA establishes global standards for nuclear safety, security and safeguards, and the UK aligns with those international standards. We make sure through our activities—be it assessment of justifications of operation or actual inspections on site—that the UK and its licensees continue to meet those high standards.



On the question on Iran, we do not monitor anything directly. We do not have any direct contact with Iran. We do not have any people focusing on Iran as such. However, because the organisation has the experts in the types of technology that we are talking about this morning—enrichment, conversion, operating reactors—and given the events happening around Iran, we provide advice to the Government on our understanding of those types of facilities and the activities that we see happening on the ground in Iran.

Q63 Chair: We heard from the previous panel that there was little or no risk to the UK directly from the strikes in Iran. Would you confirm that?

Mark Foy: I was present for the previous panel. The risks associated with nuclear facilities depend on the type of nuclear facility we are talking about. If we are talking about enrichment and conversion facilities, they have not been irradiated. It is the raw material that is being processed to enrich the uranium to a level where it can have a sustainable chain reaction in a nuclear reactor. That tends to be of the order of 3% to 5% enrichment. If those facilities are impacted by ordnance, or whatever, the impact will stay local to those facilities.

The main hazard in relation to those types of facilities tends to be a chemo-toxic hazard because of the chemical compound that we are talking about. We are moving uranium oxide into uranium hexafluoride. Uranium hexafluoride is of a specific quality. It sublimes—it can go from a gas straight to a solid. That is its unique nature that helps in terms of transportation, enrichment and such like, so that is what is used.

When uranium hexafluoride is exposed to moisture, you get fluoridic acid and that, again, is quite chemo-toxic to human beings and such like, but it will stay local to the facility. If we are talking about operating reactors such as they have at Bushehr, it has uranium within it. That uranium is the fuel. It then goes through the fission process. As part of the fission process, uranium-235 breaks down into what we call radionuclides, so it is different types of material that are radioactive, and this is on an atomic scale. Those radionuclides will have made alpha radiation, beta radiation, gamma radiation and also neutrons. It is those that cause the damage to human beings, but you have to be in the vicinity of the material.

Currently in Iran, Bushehr is still intact. It is not presenting any danger to the public whatsoever. But if you have an operating reactor that does get impacted by ordnance, there are then potential off-site consequences and the potential for the release of those radioactive isotopes, that can then damage health.

Q64 Chair: Thank you, that is very reassuring. Karine Herviou, you have spoken about the work of the agency in monitoring the nuclear activities of Iran, particularly in the context of the Iran deal which means that Iran is not to enrich its uranium to weapons grade. Israel has said that Iran has been lying to the agency and that it has in fact achieved that. Is that the case? Is your understanding of what is happening in Iran based on their co-operation and what they are saying to you, or do you have absolute



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ways of measuring the level of enrichment? How would respond to the accusations that you have been effectively duped by Iran for some years now?

Karine Herviou: I am not in charge of the safeguards department here at IAEA, just nuclear safety and security, so I am afraid I cannot answer your question. What I can say is that uranium is usually enriched to levels between 3% and 5% for use in a nuclear power plant, and that our inspectors have found some nuclear materials with inventories, including more than 400 kg of uranium, enriched to 60%. That is the only thing I can say here, because it is our inspectors from the safeguarding department who are in direct contact with the Iranian authorities.

Chair: Okay, thank you.

Q65 **Kit Malthouse:** Ms Herviou, may I probe you a little further on that? We are all trying to understand the extent, capability and reasoning behind the Iranian nuclear programme. Much of the international confidence in the control of the system is placed in the IAEA.

Are you able to give us any sense of confidence interval of your level of knowledge of activity in Iran, and whether, thus far, either when the JCPOA was in place or since, you think they have broadly played by the rules? It has been in the news that they revealed a new facility that they had not told you about. Is that usual? Or is notice normally given that they are constructing a facility, for example? We are trying to get a sense of how much of a straight talker they are with the IAEA, as opposed to not exactly playing by the rules.

Karine Herviou: I am sorry, but I am not in a position to answer your questions. In the frame of this conflict, we are just looking at the potential consequences of the strike on the installation. I could not give you information on discussions. I can just say that inspectors from safeguards have checked some inventories. That is the only thing I can tell you, because I am not in charge of this part.

Kit Malthouse: Thank you. After Mark, I have a quick follow-up question.

Mark Foy: Just to communicate what happens in the United Kingdom, we work with the agency and its safeguards department on the range of nuclear facilities that we have in the United Kingdom, to make sure that we can give the right information and the right access for the safeguards team to get assurance around non-proliferation.

But that is an arrangement between the nation itself—the national regulator—and the IAEA, so, effectively, unless the agency staff, when they come to the host country, see something that has not been declared or they have been made aware of, the only way that they will get that awareness is really through the host nation identifying the building of these new facilities, or indeed through satellite imagery and things like that.

Q66 **Kit Malthouse:** Right. I just have a follow-up question. Ms Herviou, we understand that you are not able to comment directly on the Iranian



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programme, but could you give us a sense of what the IAEA's monitoring and detection capability might be in any particular country? We heard from the previous panel, for example, that, in relation to an enrichment facility, very large power supplies are needed. So, whether the country is Iran or not, the clues are there. What does the general monitoring and detection capability of the agency look like?

Karine Herviou: In fact, to be able to detect uranium outside an enrichment facility, there is a need to take a lot of samples and to send them to laboratories. It is an alpha emitter, so it is difficult to detect. It is different from an accident occurring with a nuclear power plant, where you could have some release of fission products, and, with very simple dose-rate measurements from fixed stations in other countries, you can have an initial idea about the order of magnitude of the consequences very early on.

But, as was said by Mr Foy, usually, in the case of an accident in a conversion or enrichment facility, the radiological consequence will be low, and usually limited to within the facility's building or site. The facility staff are usually protected from the effect of inhalation and ingestion of uranium particles by protective measures like respiratory devices, but uranium hexafluoride chemically reacts with air and moisture, so it does not go outside the site. Usually, it is a very local and limited impact.

Q67 **Kit Malthouse:** So the process of inspection or checking for these things is a very physical process; it requires a human being to be present, to take a sample and all the rest of it. There is no remote detection capability.

Karine Herviou: Yes.

Mark Foy: There is a whole safeguards regime that the IAEA has in place. It consists of on-site inspections at facilities that have been designated as warranting that safeguards oversight from the agency. It also requires nations to provide regular accounts and returns of the materials stocks that they hold—special nuclear materials such as plutonium, enriched uranium, fuel stocks, spent fuel stocks and suchlike. The UK does it, and all of the nations that are subject to safeguards have to do that as well.

There are also fixed cameras where significant stores of these materials are, and there are gamma monitors that would detect if you had movement of these types of materials. The containers that certain materials are stored within can also have special safeguard seals. That is part of the process of the inspectors coming to a nation to make sure that there is no diversion of material into some proliferation of nuclear weapons or suchlike. They check the seals, and what is done is very meticulous. The accountancy is done to grams, so they make sure that there is no material diverted. But, again, it is up to the openness and transparency of the nation that is being scrutinised.

Kit Malthouse: As I say, it is very physical; someone actually has to be there.

Chair: Well, they have cameras there.

Mark Foy: The cameras are there, and they are monitored in Vienna across the world, but they do on-site inspections. We also, as the UK's regulator for safeguards, do similar inspections, because we need to give the UK Government assurance around our safeguarding of nuclear materials and that we have the stocks where we say we have the stocks. That gives the agency assurance in terms of what we do in the United Kingdom, but they do further checks themselves.

Q68 **Chair:** You said that all nations subject to these safeguards make these declarations. That includes Iran. Is Israel part of that?

Mark Foy: In terms of who is contracted to the non-proliferation treaty, I could not answer; I am sorry, Chair. I just know the UK is, and the majority of nations that have safeguarded materials are contracted. Weapon states are not obliged to be part of it because we already have the weapon. The UK, US and others do that voluntarily.

Chair: Okay.

Q69 **Emily Darlington:** I want to understand a little bit more about the wider work of the IAEA. Does it monitor the whole supply chain around nuclear enrichment? Does it monitor the sale and purchase of the uranium? Does it monitor the other materials that are needed to build the reactors or carry out the purification? You have these agreements with countries to do inspections, but are you also looking at the whole supply chain?

Karine Herviou: There is much verification and cross-checking of information and analysis to support this inspection.

Q70 **Emily Darlington:** I am not talking about Iran in particular. I am just trying to understand whether the IAEA looks at the sale of uranium. When it is dug out of the ground in Canada, does Canada provide information about who it is selling that raw material to?

Karine Herviou: There is a follow-up of all the nuclear material in the different countries.

Q71 **Emily Darlington:** Okay, so you are looking at it in its pure form, not just at the end of the supply chain when it is at weapons grade.

Karine Herviou: Yes.

Q72 **Emily Darlington:** Okay. It is just important to understand your parameters. What kind of powers does the IAEA have if countries are not co-operating with that? I am not saying Canada would do this, but for example, if Canada said, "We're not going to tell you who we're selling this stuff to," does the IAEA have any power? Where is the back-up for you?

Karine Herviou: In fact, the countries have made a commitment to be inspected and to supply the necessary information. This is then reported to the board of governors, with the IAEA reporting two times per year.

Q73 **Emily Darlington:** So it is all voluntary—there is no real back-up to that.



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The only back-up would be in a geopolitical sense, with other countries putting pressure on that country to be transparent. Is that correct to say?

Mark Foy: If the IAEA forms a view that you are non-compliant in a particular area, it will then apply pressure for you to become compliant. There are notices, I believe, that it can put in place, but it is effectively peer pressure in that respect.

Q74 **Emily Darlington:** Okay. I am just trying to understand the construct first of all. What is the role of the IAEA, if any, in the context of disasters at nuclear facilities? Does it have a role in that, or is that left domestically?

Karine Herviou: In fact, most countries have signed a convention of early notification in case of a nuclear accident, so they have to inform the IAEA as soon as possible—in particular, the incident emergency centre. This centre has five main missions. The first one is to inform the member states of an emergency situation—emergency notification—and provide information.

We will provide public information based on what has been said by the country where the accident takes place, and we assess emergency consequences and provide a prognosis of possible evolution. We also have a convention to provide assistance in the case of a radiological or nuclear emergency and co-ordination of inter-agency response. The emergency centre was activated during the Fukushima accident. It follows the situation of the conflict in Ukraine. Today, it is on alert and could be fully operational in one hour in case of an emergency declared in Iran.

Q75 **Emily Darlington:** So it could be in Iran within an hour, but it has not received a notification from Iran?

Karine Herviou: No, because there was no general emergency that involved a possible release off-site and was a threat to the health of the population.

Q76 **Emily Darlington:** I am trying to understand the safety system. Mark?

Mark Foy: To supplement what Karine said, we have the example of what happened with Fukushima. Yes, the agency was notified and did monitoring, but the international framework around regulation and governance is very supportive and collaborative.

One of my predecessors, Dr Mike Weightman, led a team to Fukushima to give support to the Japanese at the time, both from a regulatory perspective and providing advice to the Government, because of the unfortunate situation they found themselves in. I suspect a similar process would be entered into if similar things happened again in the future in relation to any nuclear facility. You see sorts of things happening around Zaporizhzhia in Ukraine, but that is about trying to get assurances to the situation on the ground there at the moment, not in response to any particular nuclear or radiological incident.

Q77 **Emily Darlington:** Finally, the IAEA has a responsibility for safety, and so will have collected experts from participating countries to assess different



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sorts of risks. In terms of its advice or risk profile, where does the IAEA put the risk of strikes?

Karine Herviou: In the strikes that have occurred in Iran, the risk of off-site releases was very low and limited. In terms of potential consequences for the health of the population and the environment, in the past day, it has not been so important. Of course, we are also looking at a possible emergency situation at Bushehr nuclear power plant.

As we saw in Ukraine, there are two types of risk: direct hit of the containment that is there to protect the environment and population against very severe releases, and loss of site power around the nuclear power plant. In that case, if the back-up systems—which were reinforced strongly after the Fukushima accident—fail, we can have a core melt accident. We know there are several back-up diesel generators that have been installed in the Bushehr nuclear power plant, which would give autonomy to provide electricity to safety systems to avoid large release and a core melt accident.

Q78 **Emily Darlington:** That is a very important point. Thank you for that.

Mark Foy: To supplement it, the agency does peer-reviewed checks of the legal and regulatory frameworks within nations on a regular basis. We in the UK have had it, and other nations have done it as well. It looks at the robustness of those arrangements, because it is a national responsibility to make sure that nuclear facilities are designed and operated to the highest possible standards, as set by the agency.

With the expertise we have in the UK, my specialists look at all the various credible hazards that we believe the nuclear facilities have to withstand. They are termed internal and external hazards. External hazards will be earthquakes—seismic resistance—extreme winds, temperature, precipitation and floods. Internal hazards will be fire, explosions, flooding internally and suchlike.

All the facilities in the UK and globally are assessed against similar types of hazards. The hazard will be of a slightly different magnitude depending on where you are in the world. We have to make sure that, in the United Kingdom, they will survive those types of hazards. Modern reactors are designed to withstand a commercial aeroplane impacting the containment building.

Karine said there is defence in depth. Containment is one of the principal ways by which you protect against the release of nuclear material. In the fuel, which you asked about, it tends to be a form of stainless steel, and it is uranium oxide within a pin that is then in a fuel assembly. The oxide pellet itself is the first containment. The second containment is the pin. The third containment is the reactor pressure vessel that it is all housed in. Then there is also a second major containment: a lot of you will have seen the doors at Sizewell B, and that is another containment.

It is defence in depth, with multiple layers that protect against a release. If one fails, another is there to back it up. As I said, modern reactors are

there to withstand the impact of a commercial airliner, but not ordinance specifically.

- Q79 Emily Darlington:** Really quickly, Karine said that one of the threats is an impact to our energy systems. We have seen attacks to our energy systems here in the UK. Mark, what are we doing to make sure that we are protected in the UK in the event of an attack that stopped energy to one of our nuclear reactor facilities?

Mark Foy: It goes back to the defence in depth principle and the systems that are there to ensure that reactors remain safe and secure. Post Fukushima, all reactors in Europe went through what we call a stress test. This involved looking at the design of the reactors and considering them in terms of a station blackout in which you lost all energy supplies to the site.

All the various sites in the United Kingdom have back-up electrical sites, either through gas turbines that will generate power or diesel generators. Defence in depth means that they also have battery supplies on the site that can last for a period of time, as well as significant stocks of diesel to make sure those diesel generators run.

If they lose power to the site, they then have an opportunity as the reactor will trip. It needs to continue cooling, because those fission products I talked about earlier continue to generate heat, so you have got to take that heat away. It is that heat that can cause problems. You need electricity to continue what we call the post-trip cool by making sure your pumps circulate the coolant.

As the regulator, we make sure they have robust defence in depth systems that maintain that cooling should the reactor have to shut down inadvertently and no longer have grid supplies coming in.

- Q80 Chair:** That is very reassuring about reactors. The main subject of this inquiry is the enrichment facility, and the UK has enrichment facilities. Where are they?

Mark Foy: The enrichment is at Capenhurst and conversion is at Springfield, both in the north-west.

- Q81 Chair:** Does everything you have just said apply to the enrichment facility as well?

Mark Foy: All the nuclear facilities, regardless of the type of process we are talking about, have to consider all credible hazards, which are the one in 10,000 year hazards. They then need to look at what systems are necessary to maintain the safety of that facility, including diesels on site.

- Q82 Chair:** So part of the threat you look at is a plane crashing into the enrichment facility?

Mark Foy: That is a special case in terms of reactors, where they have a robust concrete containment. That does not apply to those types of facilities, but as was previously explained both by me and on the earlier panel, reactors create—



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Q83 **Chair:** I know; we have discussed that to some extent, but my question is when we are considering it in comparison to the Iranian facility, if a plane crashed into the UK's enrichment facility, would it do considerable damage?

Mark Foy: It would do damage.

Q84 **Chair:** And how long would it put us out of operation for?

Mark Foy: It depends on the extent of the damage.

Chair: But it could set us back years?

Mark Foy: It could potentially restrict the production of enriched uranium.

Q85 **Chair:** For years. But that is not a risk that is assessed particularly for that facility?

Mark Foy: No. We look at the various credible hazards. In terms of uranium hexafluoride and enrichment, it does not tend to be the radiological hazard; it is the chemo-toxic hazard we are concerned about. Uranium hexafluoride, once it is released and comes out, at 60°C it tends to sublime.

Q86 **Chair:** We understand it sublimates. I am just thinking about our supply chain and the resilience, as well as what this means for the Iranians who have undergone an impact, and we are not sure of the impact of that impact.

Q87 **Adam Thompson:** Thank you, both. Coming back to the discussion of the international situation, Mark, you indicated that, if the IAEA were to suspect that a nation was non-compliant with the international agreements, it might begin to apply pressure via the international community on that nation. Ms Herviou, could you talk about the series of events that might trigger that process of suspecting non-compliance? What might lead you to believe that a nation was non-compliant with the international treaties?

Karine Herviou: The inspectors monitor the different inventories of nuclear materials and make their analysis. If there are difficulties, they would report that to the board of governors, on which many member states are represented. The board of governors could make a resolution to put pressure on the country that is suspected not to be compliant.

Q88 **Adam Thompson:** Realistically, how often does that happen?

Karine Herviou: I have only been at the IAEA for 10 days, so I am not sure that I am able to answer that question. I think it is quite rare.

Q89 **Adam Thompson:** Are we talking once a year, once a decade or once a century?

Karine Herviou: I don't know; the board of governors meets twice a year, but I don't know, really.

Q90 **Dr Gardner:** I want to continue that line of questioning. Iran is allowed to enrich uranium to 3.5%. Weapons grade is 90%. You said, Karine, that



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you have detected that it has uranium that is enriched to 60%. Did I hear that correctly?

Karine Herviou: Yes.

Q91 **Dr Gardner:** I am interested in the definitive proof that a country is making weapons-grade uranium. It is not going to admit to it. Is making weapons-grade uranium enough to make a political decision to act? As well as that proof, can you confirm that uranium enriched to 60% can be used for nothing other than further enrichment to 90%? Also, does your monitoring extend, once a country has that enriched uranium, to the development and supply chain of warheads? Can the warheads be developed at the same facility that is used to enrich the uranium to weapons-grade? That would be hard to detect.

We have heard that you can use the same facility to enrich from reactor-grade to weapons-grade uranium, and I am interested in the post-enrichment process where it is developed into weapons. You have detected that Iran has uranium enriched to 60%; can you confirm that that is a clear indication of an intention to develop weapons-grade uranium? Are you monitoring whether Iran is developing nuclear weapons from that?

Karine Herviou: I cannot answer on nuclear weapons. What I can confirm is that Iran has informed the IAEA about stockpiles of uranium that is enriched to 60%, and that has been verified by our inspectors. That is the only fact that I have here.

Q92 **Dr Gardner:** And 60% can be used for nothing else, beyond maybe storage? It cannot be reduced back to reactor grade? Why would Iran have uranium enriched to 60% if not to enrich it to weapons grade?

Karine Herviou: In fact, Iran uses centrifuge cascades to enrich the uranium, and as I said, you need just 3% to 5% for nuclear power plants, so it could have stuck with that level of enrichment.

Mark Foy: On detection, the accountancy balance returns will give you clarity on what level of enrichment and what quantities of material are held where in any one country. They will tell you what is natural, what is enriched to 3%, 5%, 20% and 60%, and the amounts. Each year through the year, you provide those accountancy returns. That would give you an indication as to, "Well, where has 5 kg gone from this? It's over here in the 20% enriched." You might have some discrepancies in the accountancies that could highlight it.

When the inspectors on the ground look at the centrifuges that we discussed previously, they are in a cascade. There are large numbers of them. They have this sort of diameter; they whizz round and it works on the principle that uranium-238 is much heavier than uranium-235, which is then siphoned off. But one of the principles of maintaining those cascades safely is limiting the volume or the quantities of uranium-235. If you have too much, it becomes critical.



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When you start off at 0.7%, the cascades are quite big; as you enrich to higher levels of enrichment, the cascades become much smaller. Your risk of criticality is increased if you do not do that, because there is more uranium-235 in that concentrated gas, so the cascades reduce. If you are going up to those high levels you will see smaller cascades.

Q93 **Dr Gardner:** Two quick follow-ups. If, in an inspection of a facility you say, "Hang on, these are really at the small end of the scale", that is a bit dubious, a bit suspicious. Secondly, can you monitor the source of the original uranium?

Mark Foy: For me it depends on whether the agency has been given access to those types of cascades, because they might not necessarily be in the same building. They could be elsewhere.

Q94 **Kit Malthouse:** I just want to clarify Allison's question. What is the function of 60% enriched uranium? Does it have any function? It is too much for power.

Mark Foy: In the western world and for us in the UK it is 3% to 5%. On 60% I would just be speculating.

Q95 **Kit Malthouse:** Nobody seems to know what you could do with 60%.

Karine Herviou: It could be used sometimes in research reactors. You can have a 20% or even more enrichment. Sometimes you need such enriched fuel for research reactors to perform experiments and also to produce radionuclides.

Q96 **Kit Malthouse:** Okay. I know the Iranians have one civil reactor for power. Do they have any research reactors?

Karine Herviou: Yes.

Q97 **Dr Gardner:** Have you verified the quantity of 60% uranium so that they could not argue that it is for research purposes? Is the quantity greater such that you would consider it would be for another use?

Karine Herviou: Everything is looked at. There is some calculation for checking what is done and where it is used and so on.

Q98 **Chair:** I know you cannot comment on Iranian uranium enrichment, but my understanding is that Iran has 400 kg of uranium enriched to 60%.

Karine Herviou: That was the stock checked by our inspector a few days before the armed conflict.

Q99 **Chair:** So we know where it was a few days before the conflict started, but we cannot say where it is now. I suppose there are two questions here. Would that 60% enriched uranium have any value on any market for terrorist actors or research activities? Can you answer that question?

Karine Herviou: No, I am not able to answer. I do not know if there is some market.

Q100 **Chair:** What would we do, Mark Foy, if we had lost 400 kg of 60%

enriched uranium?

Mark Foy: I would hope we would never get to that point, Chair. There would be serious concerns internationally if we had lost that amount of material. It is enriched to quite significant levels in significant quantities. I am confident as the regulator that we have adequate arrangements in the United Kingdom that that would never happen.

Q101 **Chair:** I am glad that you are confident, but could you just indulge me? What would our concerns be if we lost it?

Mark Foy: First: where is it, who has it, and what use do they want to put it to? The UK Government would have to form a view on all that. As the security regulator, we have oversight of security matters, and we look to the robustness of the security measures that they have on the site, so we are not just safeguarding the security arrangements that are in place.

Chair: But you are saying that there is no use for 60% enriched uranium.

Kit Malthouse: Other than research.

Q102 **Chair:** Other than research. So why would be concerned if it went missing?

Mark Foy: There are different things that you could use it for. It could be used to scare the public or whatever in relation to it being nuclear material. Nuclear has quite a lot of negative connotations associated with it.

Q103 **Chair:** But it couldn't be made into some kind of dirty bomb?

Mark Foy: Uranium is clean material, effectively. This goes back to the earlier discussion. The radiological nuclear hazard from radiation is once it has been in a reactor and starts to become irradiated and has all the radionuclides within it that can cause harm to individuals.

Chair: So we would be concerned from a security and public confidence point of view? Thank you. We are in the last five minutes, and Lauren wants to come in. Think of your questions before we end the session.

Q104 **Dr Sullivan:** On that point, we heard from the previous panel that the bomb that was dropped in Hiroshima was 64 kg, enriched to 80%. Iran has stated that it has 400 kg, enriched to 60%. In order to get to 80%, I assume you will lose some of that mass.

Mark Foy: It would still be the same mass.

Q105 **Dr Sullivan:** So it would be the same mass, but it would be enriched.

Mark Foy: It becomes denser, effectively. Sir Robin described that type of weapon; you have an explosion, and then you need a critical mass that fissions at a rapid rate and gives you that particular impact. The explosion reduces the volume into a critical mass. That is how it functions.

Q106 **Dr Sullivan:** How would Iran get to that stage? How would anybody get to that stage?



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Mark Foy: They would need the expertise within the country. We have our expertise, and other countries with a weapons programme have their expertise. I don't know what expertise Iran has.

Q107 **Dr Gardner:** I think the key question is: how much of this uranium would you need to develop that weapon?

Mark Foy: I can't tell you.

Q108 **Chair:** Thank you very much for that. Does the Committee have any final questions?

Sorry to go back to this, Mark Foy, but what is your sense of the damage that a bunker-busting bomb exploding near one of your enrichment facilities might do? You must be imagining that.

Mark Foy: Nuclear facilities tend to be quite robust, in terms of the defence in depth and the various layers of protection—

Q109 **Chair:** This is an enrichment facility.

Mark Foy: Even so, it still has multiple levels of containment and suchlike. None of the nuclear facilities is designed to withstand that type of deep-penetrating device. I mentioned a commercial airliner, but that type of ordnance is designed to get through multiple layers of concrete, embed itself and then explode.

To my knowledge, none of the nuclear facilities globally has been designed to withstand that type of ordnance. The destruction could be significant, but again it would be more of a conventional incident—a chemo-toxic incident. It would interrupt the supply of that material. The radiological nuclear danger to health comes from a nuclear power plant that has irradiated material within it.

Chair: Thank you very much. You and the previous panel have really increased our level of understanding of not only the science and technologies involved, but the risks of the nuclear programme and the US attacks on the facility. I am really grateful to you for joining us for this session.