COMMISSIONER: Welcome back. Over the next three days, we will be examining the topic of high-level waste storage and disposal and I welcome Dr Charles McCombie from MCM Consulting. Thank you, Dr McCombie for joining us very early in the morning your time.

DR McCOMBIE: Okay. Pleased to be here.

COMMISSIONER: Counsel.

MR JACOBI: The Commission today will return to the topic of high-level waste storage and disposal. As reflected in the Commission's tentative findings, safety is the primary issue in considering the long-term disposal of high-level waste. Specifically, how can the harmful elements within used nuclear fuel be isolated and contained over periods of times in the many thousands of years. The particular focus of these supplementary public sessions is how the long-term safety of high-level waste of nuclear disposal facilities is studied, tested and demonstrated and in short how could safety by means of the long-term isolation and containment be demonstrated or proven. A number of projects to develop facilities to dispose of used fuel are underway internationally and some of the most advanced on those in Finland, Sweden, Switzerland and Belgium. It is important that the Commission understands how those other nations seeking to develop facilities and their regulators have sought to satisfy themselves and the public that their proposed disposal facilities will safely isolate the harmful elements of used nuclear fuel from humans in the environment for long term.

The Commission has already received some oral evidence on this topic, in particular in relation to geological disposal facility in the rock geology at Olkiluoto in Finland in relation to low-level waste facilities in Belgium. The purpose of these suggestions is to explore in greater detail how countries abroad are studying, testing and demonstrating the long-term safety of proposed disposal facilities and how they incorporate this knowledge in to a safety case. This includes testing and analysis of how geological and engineered barriers of facilities which are integral to safe long-term isolation of waste to form over many thousands of years. An important element would be to consider how both safety cases are developed in general and where else they are used. How safety cases have been developed for projects in rock and clay geologies. What are the lines of evidence used in their development? It will also look at how the safety of proposed disposal facilities are examined and tested in a range of future scenarios, including climatic and geological changes over many years. Breach of failure of the packages and unpredictable events such as human error in the packaging process and human intrusion. The witnesses in these public sessions will include consultants' involvement with the development of projects, those responsible for the delivery of projects as well as regulators tasked with their licensing and review.

Dr Charlies McCombie of MCM Consulting provide independent strategic and technical advice to national and international nuclear waste management programmes. Dr McCombie is a co-founder of MCM and has provided consulting services to clients developing waste management programmes in Switzerland, Japan, the United Arab Emirates, the UK, Canada, Germany, Slovenia and South Africa and the Netherlands. He is also the president of ARES which is dedicating to advancing multinational initiatives for the safe and secure management of spent fuel and radioactive waste. Dr McCombie has over 45 years experience in the nuclear field, 35 of which are in a radioactive waste management. He has held positions as a scientific and technical director of NAGRA, the Swiss cooperative for the disposal of radioactive waste and as a research scientist with UK Atomic Energy Authority and with the Swiss Federal Institutes for Reactor Research. He attained his doctorate in physics from the University of Bristol in 1970 and the Commission calls Dr Charles McCombie.

COMMISSIONER: Dr McCombie, perhaps we will start in the broad. Counsel assisting has mentioned safety cases. I wonder if you would mind just taking us through the purpose and what the general ingredients of the safety case might be?

DR McCOMBIE: Okay, Commissioner first of all safety case in radioactive waste disposal has been discussed a lot in the last 10 years internationally and nationally. Basically, the definition that the waste management community has arrived at is that the safety case is the integration of arguments and evidence that describe, quantify and substantiate the safety and the level of confidence in the safety of a geological disposal facility. So these are the official words. What that really means is that you can only build a safety case, first of all, and this is really important, if you understand how the system works. So it’s not a mathematical place tool, you have to understand how the system works, you have to have enough data on the whole system to make a safety case and very importantly you have to try to quantify the uncertainties that are related to any of the statements that you make at the end of the safety case. It is really important to note that the safety of the geological disposal facility is not given by the safety case; it is given by the safety barrier. It is given by the physical and chemical stuff that works there. The safety case is the argumentation led convincingly enough, and I’m sure we’ll talk about what that means, convincingly enough for all the parties that are involved. Gives confidence that the system will operate in the way that you expect it to operate. In other words, it will be safe for all times in to the future.

So that is basically what safety case is about. The radioactive waste management community took it over from other places, originally first of all, I think the earliest – it’s a very useful tool, so that everybody wants to be the father of the word of course. The first use was in the radioactive waste field, as far as I can remember and look up, was in the early nineties, so it's a well-established concept.

COMMISSIONER: In terms of safety cases, are there other industries that use safety case to show the safety of a particular activity?

DR McCOMBIE: Yes, the safety case has got a much longer history; way back in the oil and gas industry for example, use the word safety case, much earlier. And in the UK, the nuclear area, in 1965, already every nuclear installation was required to put up a safety case. As I say, take from then to the 1990's before the radioactive waste management community adopted it but the radioactive waste management community is kind of pretty well known in taking a long time to get ideas in from outside in to where they should be. So there is an old established concept that is used in any industries, or any undertakings which can potentially be hazardous to the public.

COMMISSIONER: Okay. Before we dive down in tot eh contents of a traditional safety case, as I understand it, safety cases change over time, as they try to show different aspects. Can you just broadly talk about that?

DR McCOMBIE: Yes, well the safety case – one of the very important guidelines in a safety case is at the very beginning, you have to set that – what's called the context of the safety case. Why am I doing this? What am I trying to show? And of course that will vary during the programme. At the very beginning of our geological disposal programme, you will make a pretty generic safety case because you won't have lots of data but the context and the purpose then will be just to show that, hey look this system looks like if all the assumptions we make along the way work out, it will be a safe system. As you move down in to a programme, of course you get more and more specific and more and more detailed. For example the safety case, when you come to the most sensitive step, maybe of siting, because very detailed – and the safety case for siting has to look at the specific geological characteristics of the sites or site – for sites that you are looking at. Has to work out how it will be in the future and so on. So you want a different kind of safety case, to answer the question, hey this site, or these sites, all look as though would be useful. Then when you move down and you actually try for example to apply for a construction permit, which as many of you will know, has been done very seldom as yet in the world, but has been done recently in Finland, then the construction safety case of course has got to be even more detailed and even more convincing.

And finally, the final safety case before you start operating, is the operational safety case and that is the one where you have to have the biggest and best set of data, the highest confidence that the system will provide the levels of safety that you want. And when I say the highest levels of confidence, I mean in all of the parties involved. As a one time implementer of safety – of geological facilities, the first people who should be convinced it will be safe are the implementers themselves. If they are not convinced they should go home and do something else. When they are convinced then of course the most important, maybe in some ways, to be convinced is the regulator. You have an independent regulator that is highly competent which is the best thing you can have in any programme, then the regulator has also got to be convinced that the safety case is sufficiently convincing, or sufficiently robust. But that alone also doesn't suffice. At the end, all of the stakeholders - to use the jargon - have to be convinced. That means the general public as well, the politicians. So that the safety case will vary as you go through the repository development program in terms of the level of detail, the specificity of it and also in terms of how you present it because your key audiences will change as you move through the system, if that helps you.

COMMISSIONER: Could we just talk about geological storage then in terms of the safety case itself. What is it attempting to show?

DR McCOMBIE: As I pointed out, it's attempting to show that the geological system, if they're done correctly and done in the right place, can be safe. It's probably worth taking a couple of minutes to flip through some slides to look at what that means. If you look at slide 2, which I gave to you - - -

COMMISSIONER: Yes, we've got it up on the screen.

DR McCOMBIE: Slide 2 is a schematic that shows the safety barriers schematically in a deep geological repository system for high level waste and spent fuel. What's to notice there is that there's a whole sequence of barriers starting at the inside where you can see the waste itself which will be in some highly corrosion resistant and solution resistant form. It will be surrounded by other barriers such as the metallic or - usually metallic container. Around the metallic container there will be a clay barrier. Around the clay barrier there will be the geology. All of these barriers work in concert together, and we will come to why we think the work the way they will do. So these are the starting point of what the safety cases are. That's what provides the safety. As I said at the beginning, we have to understand how these barriers behave over very long periods of time together as well as independently.

The next overhead, number 3, shows the specific example of the Swedish safety case. Again, you can see on the diagram there, which you people can see and I can't but I think I know what it looks like. You can see in the Swedish case the schematic of how that's done there and the specific parts. In Sweden the waste form is spent fuel. Spent fuel is a highly resistant waste form that's been through a lot by the time it gets to disposal. It's been for several years in a high temperature reactor at a very high temperatures. It's been in cold storage for maybe 30 or 40 years. So the fuel itself is a good waste form. It's encased in Zircaloy casing, which is also very resistant.

The whole lot in the Swedish case is encased in the copper which you can identify there; copper being an almost passive material in the geology so that, just to throw in a number, in the Swedish case - and I think you've talked to the Swedish people before - but these containers I reckon, before they ever show any penetration, could last between 100,000 and 1 million years. Outside of the interior you have the buffer, the clay buffer, which stops the flow of ground water into the system and stops the transport of radionuclides out of the system for very long times, and then you have the geology. So all of these are the barriers in the Swedish case.

In the next slide, 4, just to give you a different example, these are the Swiss barriers again for the spent fuel case. There's not really much difference in terms of the concept. They both start from the same concept. The Swiss case, the container is actually chosen to be iron, a special kind of iron, which has a very, very slow corrosion rate in the repository itself. In the Swiss case, as opposed to the Swedish case, the geology itself is a different kind of geology. It's a very impermeable clay. So that the amounts of water which are around the repository system itself will be significantly lower in the Swiss can than in the Swedish case. So that all the different realisations of these barrier systems - there will be different weights, different components put onto the different barriers. But the idea is that at the end, when you put them all together, they give you a high level of safety with high confidence.

Then very quickly, if you look at the next slide, which is number 5, then this is important - I won't go into all the details but I just wanted to be clear I'm talking about all the barriers as if they were individual engineered barriers - waste that doesn't corrode, a container that takes a long time to penetrate and so on. But in fact in modern safety cases we don't look so much at the properties of the individual engineered parts, we look at how they work together to provide what's called here, in one of the many realisations, safety functions.

Safety functions are important because they're more scientifically derived than just the simple corrosion rate of a container. For example, to take one safety function involves a whole geochemistry of the nuclear field. That's incredible important because in a deep geological repository there's no oxygen down there. There's no oxidising waters. So you have a geochemical system which is highly reducing, especially in the Swiss case if you ion down there, which is a massive reducing agent anyway, and then there's the important part that radionuclides which are of importance in the disposal system tend to be very insoluble as long as you have these reducing conditions. They tend to travel very much more slowly through the geology if they're reducing conditions.

So the maintenance of strong reducing conditions turns out to be one very clear example of a safety function. So what safety cases will do, when we come on to this, is to analyse not just how the individual barriers react but how the combination of the physics and the chemistry in that lead to safety functions which will ensure safety over the immense periods of time that we're concerned about - physical and chemical, if that makes sense.

MR JACOBI: Dr McCombie, I think the Commissioner's question was what the safety case analysed and we've dealt with its analysis of the barriers individually and I think also dealing with them in combination. I'm just wondering what other issues at a high level the safety cases are required to analyse, putting to one side the barrier system that one might select for the purposes of one's facility?

DR McCOMBIE: The safety case does of course analyse at the bottom end or the top end is how much radioactivity could possibly get back into the human environment or the biosphere, as we call it, at any time in the future. So that's the key results which are the most easy to understand - our predictions, if you like - and lots of people don't like the word "predictions" or "estimates" - of what might happen in the far future as this whole system I've just described evolves with time. So what you will then do is, using your scientific understanding of the system, how it works and how you expect it to work, you will work out how will these decay. There will be physical and chemical decay - how that works out through time and extrapolate that into the future and the very far future and calculate then at the bottom end how radionuclides might move out.

Of course you don't just do this for how you think the system might work, you do it for how you hope the system will not work. In other words, you look at all scenarios which might possibly take place, and we may come to that. We have a reference case and a range of other scenarios which try to allow for all of the conceivable future evolutions of the system.

COMMISSIONER: I want to come to reference cases a bit later. I was just wondering perhaps whether we might deal - I think we've dealt with the characterisation of the barriers and then in combination and their performance over time but I'm also interested in understanding the extent to which it's needed to characterise - you've spoken of the waste form but I'm also interested in understanding the nature of the material with which you're dealing and the nature of its radioactivity over time.

DR McCOMBIE: The material we're dealing with in the whole thing of course is radioactive isotopes. The good thing about radioactive isotopes is that they decay by themselves by a purely physical process over time and that helps. So that after a half-life, as it is called, there is only half as much of the material there, so this is the good news. Unlike chemo-toxic materials which (are also analysed incidentally in waste management) unlike a chemo-toxic material like hafnium or lead, these really are – they are materials decay with time, they become less toxic with time. That is the good news. The bad news is that sometimes it takes a very long time. So we have a huge range of decay times and therefore a huge range of times for which the material is radioactive. On this slide – next slide 8 - - -

MR JACOBI: I wonder whether – perhaps we could – I have got a slide 7, perhaps if we start with that and then move to the chart that is a log slide, which I think will require some explanation.

DR McCOMBIE: Okay. I will just get – make sure we are looking at the same slide. This is the slide with the UK rates for spent fuel and high-level waste?

MR JACOBI: Yes.

DR McCOMBIE: What you can see there is as I said, is that the spent fuel in particular, takes a very long time to decay but it does decay. And it decays with time down to levels of the uranium material which was used to make the fuel. So in fact it decays below that with time, so that what some people don't like to hear, in fact running nuclear reactors, if you wait long enough, reduces the amount of radioactivity in the – our environment because it takes uranium fuel, makes it highly radioactive for a long period of time but eventually becomes less radioactive than it was before. The high-level waste, if you do reprocessing and the whole process is then faster because some of the heavy radio nuclides that are in the high-level waste are taken out – that are in the spent fuel, sorry, are taken out of the high-level waste and therefore the decay in the high-level waste is faster and you get back to the natural uranium levels at a shorter time.

MR JACOBI: All right. I think it might be helpful - - -

DR McCOMBIE: You should note that – sorry, if I – I was just going to mention, because that – I backed up that slide, which is a logarithmic slide and I am not sure who looks at this, but if we go to the same decay curves as most people would do on a linear slide - - -

MR JACOBI: Yes.

DR McCOMBIE: - - - then you can see on the next slide, which has got two curves on it, I think. Do you have that?

MR JACOBI: We do. This is slide number 7 we are on now. That is right, we have got that.

DR McCOMBIE: And if you look at it on a linear scale of course, then they crash to very high radioactivity decays on the time scales we are talking about, immensely fast. And the larger of the two graphs, you can see the time scales there and you can see that on these time scales, it goes down very, very fast and that is because the highest levels of radioactivity come from things like caesium and strontium which have only a 30 year half-life. So then 600 years, a factor 1,000 down already. So that these are very, very fast.

MR JACOBI: I just want - - -

DR McCOMBIE: But it – yes, sorry.

MR JACOBI: Sorry, I was hoping to pick up the implication of the right most graph of graph 7, which is on the hundreds of years plot. About what the implication of the fall in radioactivity over that time period means in terms of the need for barriers to perform in a facility?

DR McCOMBIE: Well, the implication of course is that that is the most toxic, most hazardous time but that is also the time for where the highest level of confidence, that all these barriers I just talked about, will function as they are expected to function. When you come down to hundreds of years, even the engineer barriers, hundreds of years is no big deal. Metal things last for hundreds of years, concrete lasts for hundreds of years. And of course if you think of the natural barriers, the clays are millions of years old. The geology is millions of years old. So suddenly the whole time picture looks different. We have a high level of toxicity or high level of hazard for time scales which are with a high level of confidence, easily covered by the engineered barrier and the natural barrier system that we have installed or chosen to have at the site. So that is the important part, so that we have high confidence at the time when we need it.

MR JACOBI: I was just hoping to move from that to then deal with, we know from what we have read, that the safety cases analyse the performance of these facilities over time scales of more than a 100,000 years, and in fact in some cases I have read, many hundreds of thousands of years and out to a millennia. If that is the case, why is it necessary to conduct an analysis over a period of time out to 100,000 years or beyond in view of what we are seeing in perhaps the left most version of graph 7?

DR McCOMBIE: It is because the hazard drops to levels which are not very alarming compared to many other stuff, but it’s not zero. So we do a proper job. We want to make sure that the hazard “all times in the future” will never be significant to human beings. And as I say, part of the inventory has a very long half-life, has a very long hazardous lifetime, so we carry the calculations out until we are sure that even if everything is analysed out to these times, then again, back to the (indistinct) and the safety case, there will never be any significant hazard to people who live anywhere in the neighbourhood of where a repository has been – proper repository has been built and sited. So the time scales, I think on the next overhead, which you have – yes, I have a different numbering system. But on the next overhead you have got, we go back to the safety functions again, overhead 8, yes?

MR JACOBI: Yes.

DR McCOMBIE: And without going in to all of the detail on overhead 8, what this does, it takes the safety functions that I looked at before and shows you, in the bottom scale, how long, over what periods of time these safety functions actually work. And you can see that we expect some of these safety functions to easily work out, right out to the long time scales which you have just mentioned, to the ten, to the five and ten to the 600,000 to a million years. The geochemistry won't change in that time. We know, we can analyse, we can look at groundwaters which we know there are hundreds of thousands of years old. We know what the chemistry has been. We can look at the geology of clays which are hundred – Swiss case which I know most intimately, to 180 million years old. So they are off of this scale. So that all of these very long time scales are covered by processes, by safety functions which function over these long time scales. And if you look up in the left hand edge of this slide, you will see that for the hundreds of years time scales, we are so confident there that we use terms like complete containment, or immobilisation. So that on all of the container designs which are considered throughout the world for high-level waste or spent fuel, then there is complete confidence that there will be no leakage at all. The containers will not be penetrated within this hundreds to thousand time – you know, time scale that we talked about.

To be exact in the very long lived containers like the Swedish ones, as I said, their assumed lifetime is 100,000 years, which they think they can prove very robustly. In our Swiss case, it's at least 1,000 and we think 10,000 years before the containers even go out. So you have this, as I say, enhanced level of containment and more importantly perhaps, an enhanced level of confidence in the containment over these hundreds of years period, where the hazard might be presented to humans is at its highest.

MR JACOBI: Can I just come back to safety cases generally and I am just interested what you have discussed is that there is now an accepted concept of a safety case and I am just wondering about whether there are now agreed criteria that safety cases must address? And whether there is an agreed level of satisfaction that you must have, that is in terms of the level – the level to which you are persuaded or convinced that they will be safe?

DR McCOMBIE: Okay. There are agreed criteria for safety cases. The criteria differ slightly around the world but only very slightly. The criteria is most often expressed in terms of a radiation dose. The dose which is most commonly used is 0.1 millisieverts per year if you're anywhere in the world except the USA and 10 millirem, which is the same number with other scale in the USA. Some countries go a little bit higher than that. But that's the dose level that's commonly used - and you'll see some examples afterwards - commonly used as the criterion for safety. You have to be assured that this dose level will never be exceeded at very long times into the future or at all times into the future.

The other way to express it is as a risk level, and commonly it's one in a million per year is the risk level. The dose level that's there is more or less slightly higher than one in a million per year but it's about the same order of magnitude. On the slide 9, to give you some information, what you can see there - it's a complex slide which people might want to look at longer in isolation afterwards - but you can see the middle part is where we're talking about for deep geological disposal facilities, the dose in millisieverts.

Between the two dotted line you can see the number I just mentioned, 0.1. That's in, as I say, many countries the kind of level we're looking at. To give you some perspective on what that really means, you can look to the right of that and you'll see that natural background anywhere in the world starts around 30 times this maximum allowed level and goes up to some 300 times around that. So that from 0.1 millisievert you can easily have two to three to 10 millisieverts at different places around the world.

If you look inside the dotted line, you will see that they give another example on the bottom of the slide that a long-haul flight, which Australian must know more about than most people, will give you of its own about the same as you're allowed to have per year from a deep geological disposal facility; in other words, 0.1 millisieverts. If you want to be ridiculous, if you like, if you go down another factor of 10 to 0.01 to the left of the left-most dotted line, you will see the numbers there which have been described as being below concern, half-humoristically we have included at the left side, near the bottom, eating a banana which has got calcium-40 inside it and gives you that level. I think eating a banana is much the same as sleeping next to your wife or anything else because people also have radioactivity in them.

Then at the big arrow on the left it shows you, and you'll see the specific examples of this, the kind of examples which are being produced by safety case analyses all over the world. So that the expectation values for doses from a well-sited and well-constructed geological disposal facility are factors of a hundred to a thousand times lower than the criteria that I just mentioned, which means factors of 10,000 lower than natural background.

MR JACOBI: That will be a helpful point in fact I think for us to pick up, the concepts of the reference case and the scenario cases that you might develop in a safety case. I'm just interested perhaps whether you can explain what is a reference case and then explain that back to the image which is in 9 and the extent to which a reference case gives you a particular output that one can then use to compare to the regulated limit, which you've explained is .1.

DR McCOMBIE: The reference to - - -

SKYPE TECHNICAL DIFFICULTIES

ADJOURNED [3.06 pm]

RESUMED [3.06 pm]

COMMISSIONER: We're back online again. Thank you.

MR JACOBI: I think I might have to ask the question again. That is, I was hoping that we could pick up we've heard about the concept of a reference case for the purposes of a safety case and I'm just interested to understand how a reference case is developed and then what the relationship of that is to any of the outputs that are shown in figure 9.

DR McCOMBIE: The reference case basically is the case where the system behaves as we expect it to behave; in other words, it's the normal evolution of all the barriers that we've talked about. So we assume that the geology will behave like we think it will based on extensive field tests and experiments and measurements that we've done. We still think the corrosion rates will be as we think they will be. We assume that clay will work as it should do and we put all of these things together and culturally then if it all works like that, what will the release rates from the repository - what could they be in the future.
Of course we then convert these release rates into doses that compare with the volume that we just mentioned, 0.1 millisievert.

MR JACOBI: I'm just interested in the basis on which those estimates are prepared; that is, I've read that they're prepared with respect to things like heat dispersal and stresses of water movement and so on. How are those individual estimates calibrated or calculated?

DR McCOMBIE: First of all, I should say that they're not single point estimates. Really important is that even in this what we call a normal case/a reference case/normal evolution, we don't want to say we know the exact volumes of any of these parameters. We assume ranges for all the parameters and the ranges are chosen to be as conservative as we think they should be. In other words, we don't assume that everything will work in the best possible way. We try to bracket the expected scenario and then I won't use the word "worst cases", but what the values might be if things don't work out quite as we thought they would. This is also in worst case.

MR JACOBI: A pessimistic basis?

DR McCOMBIE: Sorry?

MR JACOBI: Do you mean a pessimistic basis?

DR McCOMBIE: Yes. "Conservative" is the word we use but I think "pessimistic" is a more normal word. So we pick a pessimistic set of data and a reference set of data and we use all of these data in the reference case still. Most programs now actually run very complex probabilistic assessments where they pick out all these values at random within the ranges allowed and then calculate through the whole system and look out for the whole spectrum of potential plausible data for any of the processes involved. We work out the spectrum and then we wind up with a range of values, all of which are for the reference case.

On top of that, we look at other kind of cases which I think we should come to in a minute. But before that, I think it might be interesting for some people to show you where this data comes from. We don't dream them up or whatever. This is the most extensive and most expensive, both parts, of any geological disposal program, is getting the data that you need to put into these reference cases, to put into these safety cases. I put in a set of overheads to try to illustrate this point. I think they're overheads 12 onwards. Yes.

MR JACOBI: It's headed Geoscience in Rad Waste Disposal Assessment?

DR McCOMBIE: That's right, yes. So I'll go quickly through them. This is just to show that this is highly complex. The geological part is mostly the most expensive and extensive part where we look at all of the processes which will influence the calculations that we're going to do at the end and we go out and try to measure them as much as we can, directly measure them, and the measurements can take place in various circumstances.

The next slide after the Geoscience in Rad Waste Disposal shows you a picture in a graphic sense. I've called it High-Tech Geology. It shows you as examples the expensive end of doing site characterisation work, if you like. Drilling technology. When you drill deep boreholes to a depth of 1,000 and 2,000 metres, as we have done in Switzerland and other places also in the world, this is a really expensive and really high-tech job.

Drilling the holes is the easy part. The measurements in the holes are the difficult part. In fact on a cost basis, it costs you more to do measurements than to drill the holes, and a single hole - in our case in Switzerland, originally when we started out it cost up to between 10 and 20 million US dollars for a borehole and you need a lot of these boreholes, indeed several.

On the right-hand side you can see a seismic campaign. Again, boreholes are good, but they're point data. As you realise, it's one single borehole and you have to do several. If you want to extrapolate between these boreholes to find how the geology looks on a larger scale, one of things you can do is called geophysics, and these heavy machines which you see set up kind of quasi, mini earthquakes, vibrations in the earth, measure the reflections from all of the different geological strata, geological media down there and us a very advanced computer analysis, put these together and produce what's in the bottom right-hand corner, a 3D image of the whole of the site.

So again, this is a massive campaign involving hundreds of people, involving many, many tens, if not hundreds, of square kilometres there to get the data. These data from, really, field measurements are backed up on a finer scale, a smaller scale, very often by rock laboratory measurements. That's what's shown on the bottom left picture where the guys in the protection suits - that's in Switzerland. We were actually doing underground measurements in a deep facility which is not a waste disposal facility, which is purely a research facility, and there we're measuring how radio nuclides actually do move in a real geological setting. This is of course is key data that goes into the analysis that we do afterwards.

The rock laboratories themselves, several countries in the world have had them. The next overhead shows the Swiss rock laboratory at the Grimsel again, some illustrative pictures again. This has been a program which has run since 1984, has involved something like 12 or 15 different countries from around the world and has spent lots and lots of resources, lots and lots of time investigating exactly how you can characterise the underground and how all the processes that we're interested in will take place in the underground and this goes right up to doing full-scale experiments.

On the leftmost one there is a full-scale buffer experiment where we actually do an underground mock-up of what the system will look like. These are the kind of experiments which are done in the rock laboratory. Of course these are also backed up by experiments done in what you might call conventional laboratories, in other words, radio nuclide laboratories around the world, and most research centres have got the facilities for doing this. ANSTO has the facilities for doing it and every country has a nuclear research facility.

So there we measure really on a lab scale and now we're talking lab-bench scale. So you can see we go from centimetre scale in the traditional, if you like, laboratory, to metres, to tens of metres scales in rock laboratories, to 100s of metre scales, to kilometre scales in the field. This huge data collection exercise is why the characterisation of a site, for example, up to the stage where you're ready to apply for a construction licence, or even a site licence, can take and has taken and will take years, five years, ten years. The original, first pioneers there, the Scandinavians, have taken nearly 20 years. So not anybody's guessing what might happen. This is based on the best data that we can have.

Having said that, of course the element which is missing in these direct experiments is the temporal, the time element. If in our field experiments, which are some of the longest experiments that have been done scientists - at the Grimsel we have experiments which have been running for 25 years, and there are experiments with leaching of waste materials which have been running for nearly 40 years in some places.

But what's 25, 40, 50 years compared to several hundred years, several thousand years, several tens of thousands of years? This is a very correct question which we often hear, and that's why we have spent a lot of time, and a lot of increasing amount of time is being spent, on the next place we go for data, and that's to what we call analog. Again, if you look at the next slide there, The Analog. Analogs come in different species. By an analog, we mean as in English, normal English. We mean something that looks like something else. In our case, we're looking at some material, for example, that looks like, simulates, is an analog of the materials which we put into our radioactive waste repositories.

We have what we call archaeological analogs, and that's what's in the slide you should be looking at now, and the leftmost ones, the nice graphic of the ancient Britons throwing nails into a hole in the ground, is part of - I can use my Scottish background here - is part of a horde of nails which was buried by the Romans fearing that they would be overtaken the Scots in northern Scotland 2,000 years ago. Some tonnes of iron nails, big iron nails, I should say, 25 centimetres long, were buried in the ground 2,000 years ago and they were excavated 2,000 years later and we can measure - we don’t have to guess - we can measure how much they have corroded, and what we find, to our relief, if you like, for confidence building, is that they have rusted.

The ones on the outside in particular have rusted, but the ones on the inside have hardly rusted at all after 2,000 years. Why? Because the dual-chemical environment I talked about before has been very conducive to non-rusting; it's been very reducing. The rusting ones on the outside have used up all the oxygen that's available; the ones on the inside have therefore not corroded, or not significantly corroded, over that time.

Along the bottom of the slide you can see other examples there. You can see a huge bronze hoard that's even older. Again, we've done lots of work on this from bronze hoards from the Bible area where these artefacts are thousands of years old. If you move to the extreme right, this beautiful fish which is actually a perfume bottle is in Egypt and again thousands of years old glass. Now, it's not the same glass that we use in high level waste but it's a glass. So it's an analogue of the glasses that we use. So that has worked very well.

The most impressive one I think is the top right-hand corner, which then becomes a natural analogue. This is a forest in Italy, Dunarobba, which was enveloped in tight impermeable clays very much like the clay that we intend to use in some geological repository concepts. This forest was enveloped before it could decay away so that the trees in this forest stayed preserved for one and a half million years. They're not preserved like fossil trees. We all know what fossilised wood looks like. This is not fossilised wood. This is natural lignite wood. This wood, you can polish it, you can make coffee tables with it now if you wanted to. So this is again a confidence building aspect which shows us that the tight clays that we tend to use are capable of the kind of preservation that we would like them to be. Of course it doesn't prove that it will happen in our case. It doesn't prove it will happen but it certainly demonstrates that it can happen.

The last of these confidence building, I use the word, slides is the next one which - - -

MR JACOBI: Slide 16.

DR McCOMBIE: Yes. This is a schematic of a really interesting example of an analogue not just of a single barrier or a single safety function but to some extent an analogue of a whole nuclear waste repository. This is the Cigar Lake uranium deposit in Canada. Cigar Lake has the highest uranium enrichment of any deposit that was ever found, including those in Australia. So you have some competition here. The radioactivity of this uranium deposit is such that it can only be mined using remote mining techniques. However, the uranium deposit itself is deep underground and by chance, if you like, is surrounded by a halo, a surrounding medium of clay, of impermeable type clays like we want to use. The interesting part of this particular analogue is that if you look several hundred metres up to the surface there and then after all of these millions of years afterwards, there is no surface expressions.

There was none of the uranium in any measurable quantity has reached the surface. Why has it not reached the surface? Because it's been held back by exactly the same kind of safety barriers or safety functions that we want to use in deep geological facilities. In other words, the uranium itself has been very highly insoluble. Why? Because it's reducing conditions. There is no oxygen down there. Secondly, if the uranium did come into solution with the groundwater, it will be trapped. It will be held back by the clays; exactly the same kind of clays that we want to use.

So again you can see that this extrapolation of all of the measurement data that I described before. Extrapolation via the mechanism of archaeological and natural analogues is all part of the confidence building process which is a really, really important part of preparing and presenting the safety case.

MR JACOBI: Can I come back to the - we spoke of a reference case and that being an expected result but perhaps estimated on a conservative basis. I'm interested in now moving on to scenarios that might be thought to be less likely and I'm just interested in the extent to which it's necessary in a safety assessment to deal with less probable events.

DR McCOMBIE: Yes, it is. I'm looking for the one which I gave you on this. We look at - - -

MR JACOBI: Is it number 11?

DR McCOMBIE: Yes, I'm looking at number 11, sorry, which is not very graphic. In fact, if you can, you could look one back to number 10 very briefly.

MR JACOBI: Yes.

DR McCOMBIE: Number 10 just shows you graphically - it's a kind of illustration for people who are not into the details. It shows you on one level the kind of scenarios that we do look at even when we look at what we call normal evolution, a reference case. So the graphic there shows you that included in what we call now normal evolution are things such as climate change. Climate change will happen. In which direction it will happen nobody knows exactly. So what do we do again, to use this example, we say that climate change is part of our reference.

We do not assume the climate will stay constant forever. So then we look at extreme pessimistic or extreme variations of climate. For example, in our Swiss case we look at Swiss tundra scenarios for. So Switzerland would look something like the northern tundra areas now look (indistinct) ice age. We look at these kinds of scenarios already there. We look at scenarios which cover issues that we cannot exclude but would not particularly like to have, such as the fault which is shown on (indistinct)

We go to a lot of efforts to try to show that there will be no faults, geological faults, around the system which we do not know about but we don't assume that that will necessarily be the case. We look at scenarios where maybe there is a fault just outside the region that we've looked at or we can look at in great detail. So again, this simple graphic shows you already that we don't just look at one reference case with all of our assumptions.

The next slide that you wanted to look at before is more explicit. This is the one with the Swiss non-reference cases. If you look down that slide, then you will see a range of additional scenarios as they're called there. These are scenarios where we don't expect things to happen but they cannot be excluded. Sometimes we don't even see very easy physical mechanism to make them happen but we do not ignore the fact that they might happen. So that as you look down the whole list of scenarios there you will see various features, events and processes which we take into account, that we assume might be a case which might take place which do not correspond directly to our reference case. So we look at all these kinds of scenarios to - - -

MR JACOBI: Sorry, Dr McCombie, just to relate two things together - - -

DR McCOMBIE: Yes, of course.

MR JACOBI: - - - am I right in understanding that the range of outputs that are shown in that graph across a wide range of scenarios reflect the range that's shown back at slide number 9, which was the typical calculated impacts of a repository on the far left?

DR McCOMBIE: Yes, that's right. This simplified example is a collection of many, many results, all of which would give graphs like we looked at before showing the release rate for a specific scenario. So we do these multiple, multiple calculations and the band width that you see on the slide that you're looking at now reflect the range of results. The intention is to produce a system where these range of results will always be well within the criteria which we talked about before. As you can see there, we've entered in the typical criteria 0.1 millisievert and also, still for reference, the natural backgrounds in Switzerland, again with some level of confidence that none of these scenarios will exceed the criteria.

What you will expect to happen of course is that some of the more extreme scenarios which we don't expect might have a smaller margin of safety than the others. But in fact if you look down the list you'll see that all of them, however conservative, however pessimistic, have a margin of safety to the criteria itself of at least factor 100 and sometimes factor thousand and more.

MR JACOBI: I'm just wondering perhaps if you can take us to the next step from this, which is how does one reason from each of those individual outputs to a conclusion that you're either one way or the other assured that the system would be safe over its lifetime?

DR McCOMBIE: First of all, the bar chart, the diagram that you're looking at now - I don't think we looked at the simpler charts from calculating a specific scenario. These are the slides that were numbers 18 and 19.

MR JACOBI: Yes.

DR McCOMBIE: So if we look at 18 first of all.

MR JACOBI: Yes, we have that.

DR McCOMBIE: So these are Swiss results. They're again the ones that I know best. This is for one particular case. I'll just give it as an example. This is actually for high level waste rather than spent fuel, but the spent fuel looks very similar. We can talk about that later. Again, in here you see on one axis the time scales and in Switzerland we go out to time scales which are effectively infinite, if you like. We calculate these long time scales because we can if calculations can go that far. They show that even if you go out to these time scales we don't get any sudden, unexpected behaviours.

There was for many years a big debate about whether it's sensible to even look at time scales like 100,000 years, which is 10 to the 5, if you see on the time scale there. Some countries said that, "That's really silly, nobody looks at 100,000 years into the future because you can't." We said, "We do, because we can." That's because we're in a different situation. We're not on the surface of the Earth. Nobody will make any guarantees on what happens on the surface of this Earth 100,000 years in the future, but any geologist will put his hand in the fire for some things that will happen 100,000 years in the future deep in the geology because 100,000 years is a very small amount of time in a geological time scale.

So that's why we think we can run these calculations out to these kind of time scales - probability extrapolation.

MR JACOBI: I'm just wondering perhaps whether you can give us some assistance with the interpretation of that chart. We see a series of coloured curves that emerge at a point in time some time between a thousand and 10,000 years. I'm just wondering, could you explain what that shows?

DR McCOMBIE: So the assumption is that the system starts operating the way we think it will. All of the processes run the way they will. The corrosion happens and the groundwater gets in slowly, the container is breached at some time in the future but there's still no impact at the surface. In fact the first impact at the surface happens after all of this breach happens, after some radionuclides get into the groundwater and the groundwater is transported to near the surface. The groundwater at the surface is consumed in some shape or form through eating vegetables or from drinking water by people and then these people are then subjected, because of that, to a radiation dose, as we talked about before.

What you see on the lines there is the dose that they will be subjected to if all of these things took place and when it would happen. What you can see is that there are three types of doses there and that's from different radionuclides. The radionuclides have different properties in terms of how slowly or less slowly they move through the whole geological system. What you notice is that unfortunately on this representation here they're not labelled but the earliest releases - that's the first bar - the first bar that appears is the highest one. These are from mobile fission products. These are not from the famous plutonium and so on that people are worried about, or uranium. These are from things like iodine-129, which is actually a fairly harmless radionuclide but is very, very long-lived - 80 million years, to be exact - so that effectively it doesn't decay. But what it does, it comes out very, very slowly and in very, very small quantities and then, according to this calculation, after some tens of thousands of years it appears in our calculations.

Of course it would never be observable in any of these shape and forms. If you want it to be measurable, even 0.1 millisieverts is not measurable. But in our calculations it appears it's some tens of thousands of years. It appears until all of it slowly comes out over some hundreds of thousands of years. That's where the peak is on the highest curve. Then it's over in a deep curve and disappears into the environment. So that's for the most - - -

MR JACOBI: If I'm correctly understanding the peak, the peak is about one one-thousandth of the actual regulatory limit.

DR McCOMBIE: Yes.

MR JACOBI: Is that right?

DR McCOMBIE: It's ten-thousandth of the regulatory - - -

MR JACOBI: Sorry - - -

DR McCOMBIE: One-thousandth, yes.

MR JACOBI: That's right.

DR McCOMBIE: Just some thousands of the regulatory limit is the peak. That's for the highest dose producer. All of the other bars you see getting smaller and further out are from the various other radionuclides that come out. Then the ones that you can hardly see or not see at all are from some of the long-lived radionuclides. For example, the ones which create most public discussions, something like plutonium, will never appear on this scale here. Plutonium has a 25,000-year half-life. So after a million years you'll never see it anyway and it doesn't move in the kind of distances that we're talking about here. So this is one set of calculations for one particular realisation of all of the data points that we talked about. What then happens of course is if you take many realisations of that, you get to the ranges of values such as we saw before on the bar charts. This is one particular example taken from Switzerland.

The next overhead, this one, just illustrates that the Swiss results are not unique in any shape or form. Do you have this one now?

MR JACOBI: Yes.

DR McCOMBIE: This is in five different countries. So again using the same kind of display and the same axis there, you can see, without going into all of the details, that these different results - KBS is from Sweden, SKB is also from Sweden, TVO is from Finland, AECL is from Canada (indistinct) Line 1 is from Switzerland, and H12 - the one at the bottom - is actually from Japan.

MR JACOBI: These are all different barrier concepts.

DR McCOMBIE: These are all different barrier concepts. The same basic concept, different realisation of the multi-barrier concept. The Japanese one is pretty similar in fact to the Swiss one with an iron container. The Swedish and Finnish ones are very similar. The Canadian one is pretty different to all of them. But what you can see in all cases we lined up - not just below the regulatory guideline but a long way below it. So that's why the calculated results as such tend to enhance our confidence in the long-term safety of a deep geological facility.

MR JACOBI: Can I just quickly - - -

DR McCOMBIE: As I said - yes?

MR JACOBI: Can I quickly pick up a couple of scenarios that we haven't dealt with? We've dealt with the scenario of climate change and glaciation and we've dealt with the decay and failure of engineered barriers. I'm interested in the context to which mistakes, that is, mistakes in the original design of engineered systems, or unpredictable future events like boring into facilities, is taken into account, or how that can be taken into account.

DR McCOMBIE: Yes. These are all taken into the altered scenarios in all cases. In the Swedish case, they use the best example probably for the engineered mistakes. Because the Swedish case's safety case has a strong reliance on the absolute containment by the copper-steel container, then there was extensive work done on the failure probabilities of these containers.

They will be manufactured to the highest possible engineering standards of course, and they will be quality assured in the laboratory and they will be checked before they go in, but it's not assumed that they will not fail. So failure rates are assumed for all the containers and these failure rates will have to be justified to the regulator and to anybody else who is concerned. So they can't be optimistic and therefore they usually choose to pessimistic, so failure of the barriers is assumed.

The interesting case of somebody drilling into the repository has caused huge discussion in many different fora over the past several years. This is called the human intrusion scenario, and I personally worked on that quite a lot, even in a US state, and what we said there is that lots of measures were taken to reduce by a long way the probability of anybody ever drilling into a deep geological repository. So it's in a remote location. You will leave records where it is. You will ban, as far as you can into the future, any drilling activities there. You will site it an area where there are no very obvious natural resources that might lead to incitement to drill and so on.

So you take all of these precautions to try to reduce the probability, but we still ask ourselves the question: what if you do all of that and somebody does drill into it? So we even look at this extreme scenario and what will happen. If somebody drilled into the repository, the first thing is that mostly he or she wouldn't hit any of the waste canisters at all, but would hit some strange material down there which would make them aware that, hey, there's something here.

In a worst worst case, if they did hit straight into the spent fuel, for example, and bring it to the surface, somebody will get hurt, a driller, yes? There's no perfect system anywhere in the world for any technology. So it's undeniable that a driller who happens to drill up, some thousands of years in the future, a lump of radioactive material will get irradiated, but if he's capable of drilling down thousands of metres with high technology and so on, he's going to know pretty quickly what it is, and that's one of the accident scenarios that's looked at.

So we can't say for the single driller being exposed, yes, but what we can do is ensure that even if there is now a hole, if you like, a pinprick or a hole through the repository, this will not destroy the safety of the system. So we haven't built the repository something like an inflated balloon that will be burst by a pinprick. We built a system that you can poke holes through and it will not leak. So in the US system example where I worked very closely, we said that even after somebody would do that - forget the probability; just assume that he did do it - then any leakages, any health effects from this repository should not be in any way significantly increased because of this single hole that's gone through the facility.

So that's what it's all about for what we call human intrusion, and of course we only look at what we call inadvertent human intrusion. If somebody far in the future decides he'd like to go in there and excavate the repository, then that's a societal decision which is totally different. It would only be done if people wanted to do it and knew they had the technology and the reasons.

COMMISSIONER: Thanks, Dr McCombie. We might just finish with one sort of broad question again. How well defined does the barrier system have to be when we make the first general safety case?

DR McCOMBIE: The first general safety case, especially nowadays, doesn't have to be finally defined. When you make a first safety case you can still keep options open. In particular in many countries you keep the geological option open and many countries have a choice of geologies, so that when you first start to go down a road towards a geological repository, then you don’t have to say, "We're going to build a repository and we'll build it in this granite somewhere or this clay somewhere."

You can say, "We're going to build it," but then you can make - especially based on the decades of experience now, you can say, "This is the kind of system we'll build. These are the options we will keep open," and so on, and then you can say, "And these are the data limits which we will have to meet if this system issue going to be safe."

So you wind up with something which I personally have called a conditional safety case in the beginning. So you can wind up saying, "This system" - and this has been done in Switzerland de facto. When we did our first safety cases way back in 1985, then the regulator came along and he said, "Hey, this is really good. The work is good, the science is good, you've got lots of data there, but you don’t have enough data to really convince us you can start building this thing. What you've done is you've got enough data to convince us that we'll let you go out there and look for the data that's missing."

We assumed. We said that the rock would have this range of properties and the answer of the regulator wasn't, "No, no. That doesn't work." Their answer was, "You haven't shown that yet. Go out and get the data. So the safety cases, as you move through the system, will have a different degree of confidence, robustness in the data which you're actually using.

Now I work with many developing programs around the world and what we tell them is that it's never too soon to start a safety case, start right now, start with what we call a generic safety case, start with a set of assumptions of what you might do and by doing that, it will help you define what work, in particular what research, what development, what measurement work you have to do in the future," and as I pointed out earlier in this conversation, then the work you have to do is the big resource-using part of it. It takes a lot of the time; it takes a lot of effort. If you could guide this work using a safety case as a guide, then you can save yourselves lots of trouble; you can save your regulator in the future a lot of headaches when he comes to review your data.

COMMISSIONER: Dr McCombie, thank you very much for your time this morning. It's been very useful.

DR McCOMBIE: Okay, thank you. I hope that's helped you and I wish you luck with your endeavours. Thanks a lot.

COMMISSIONER: Thank you very much. We'll adjourn now until 16.30 when we will have Dr Maarten Van Geet from ONDRAF/NIRAS from Belgium.

ADJOURNED **[3.48 pm]**