NUCLEAR FUEL CYCLE ROYAL COMMISSION

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MR KEVIN SCARCE, Presiding Commissioner
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SPEAKERS:

DR ERIC LOEWEN, Chief Consulting Engineer at GE Hitachi Nuclear Energy

TRANSCRIPT OF PROCEEDINGS

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investigating opportunities and risks for south australia

COMMISSIONER: Good morning. We'll convene. Topic 4, low carbon energy generation options. I welcome from the US Dr Eric Loewen. Thank you for joining us Dr Loewen.

DR LOEWEN: Thank you for having myself and my company, GE Hitachi Nuclear Energy, participating in the Commission.

COMMISSIONER: Thank you. Counsel.

MR JACOBI: Dr Loewen is the chief consulting engineer at GE Hitachi Nuclear Energy where his current work is focused on the development of GEH's PRISM reactor, a small modular reactor designed to recycle spent nuclear fuel. Dr Loewen served as the president of the American Nuclear Society from June 2011 to June 2012. He obtained his masters in nuclear engineering and a PhD in engineering physics at the University of Wisconsin-Madison. The Commission calls Dr Eric Loewen.

COMMISSIONER: Dr Loewen, I see in your submission to us that you noted that you expect to be commercially available, this PRISM reactor, in the next two decades. I wonder if you could outline to us broadly what studies and technological developments need to be completed before your reactor might be licensable and therefore commercially available.

DR LOEWEN: The PRISM reactor initial development started in 1981 with a US-government-funded program that ended in 1994. GE Hitachi Nuclear Energy continued the development from 1994 to 2000. The government policy of the United States changed in 2006 and we did more development. So, Commissioner, to specifically your question, what needs to be done is the design needs to be taken in front of a regulatory body for the regulation, and in that process, there are some demonstrations and validation of the technology that's required, and then the technology would be ready for deployment in Australia.

COMMISSIONER: So the process you expect to move through would be to have it licenced in the US?

DR LOEWEN: We would licence the reactor in the country of origin. So in our work with the United Kingdom for the disposition of plutonium we looked at their regulatory process. I realise that the regulatory process in Australia does work to control a test reactor and so to move into the power reactor regime would require different approaches, and we have some suggestions on how the Commission could approach that.

COMMISSIONER: All right. So I take it from your evidence that most of the studies and the technological developments that are needed are mostly completed.

DR LOEWEN: Yes.

MR JACOBI: Perhaps if we can come to deal with some aspects of the design of the PRISM reactor, and I think we've got a slide that might pick this up, our first slide. I'm just wondering about whether or not you could identify the key features of the PRISM reactor, and we might move through and deal with some of the specifics of those key features.

DR LOEWEN: All right. The slide that we have up is a picture of the PRISM power block that's two reactor vessels side by side on one seismic isolation block. What I mean by that is we have one concrete slab that has seismic isolation bearings, similar to what's used in buildings in Los Angeles and Japan, and that allows it to be more robust during a seismic event. As you can see, the reactor vessels, the very top of them, are subterranean. They're about 50 feet below the grade of the land and that allows us to have the ability to remove heat by using the laws of physics.

The cut-out there shows what the reactor vessel looks like. So all of the primary coolant (indistinct) is contained in one vessel. There's no drains, there's no valves, there's no pumps. There's no pipes that external to that. So when there's concerns about losing the coolant in a reactor system, the PRISM reactor cannot have a loss of coolant accident.

MR JACOBI: We'll come back to issues of safety in a moment. I want you to unpack the explanation that we just had with respect to a LOCA. I just want to pick up some aspects with respect to the design of the plant itself, and I'm just interested its overall size compared to a conventional light-water reactor.

DR LOEWEN: The power block you see there, that exact footprint is - forgive me, I don't know my metric units, but it'd be about four acres US or so. So it's a pretty small footprint. What is not shown in that picture is the balance of plant, which is the turbo and the steam turbine. So this power block is where the steam is produced in the system. Then that goes into a turbine generator and so that generates, in round numbers, about 600 megawatts electric to go onto the grid. So this advantage of having two reactors support one turbine allows maintenance to be done on one reactor and you continue to put 300 megawatts electricity on the grid.

And the one unique feature that's different about PRISM compared to other sodium-cooled reactors around the world is in that very small picture at the bottom of metallic fuel. So that's a fuel that was developed in the United States. That fuel is more reliable, it's more economic to fabricate, and it gives better performance to the reactor system. That's one of the key features that's different.

MR JACOBI: Yes. I'll come to the fuel that's used in a minute. Coming back to the image that we see here, does that contain both of the reactors or do you need, essentially, two of those for a turbine building attached - - -

DR LOEWEN: I'm sorry, it's the (indistinct) not through the - you see is two reactors side by side and one reactor produces 300 megawatts electric, the other one is 300, and what is not shown in that picture is the turbine generator. I have that in a future slide that we can take a look at. I apologise.

MR JACOBI: Okay. No that's all right. We've heard some evidence speaking to other companies that design and construct power plants with respect to issues of resistance to aircraft impact. I'm just interested in the extent to which that particular characteristic has been incorporated into this design.

DR LOEWEN: A PRISM reactor is very resistant to airplane impact, because as you can see, we're 50 feet below the grade of the land, and so I'll take 50 feet of dirt any day on airplane impact as far as affecting the safety parts of the reactor vessel.

MR JACOBI: And we've heard that expressed in terms of its ability to be licenced either under the European or American standards vis-à-vis aircraft impact. I'm just interested to understand the extent to which that's been demonstrated or the extent to which its GE's view that it would meet those requirements.

DR LOEWEN: When they come to airplane impact as far as licensing any nuclear facility, that started after the tragic events on 9/11 and that information is safeguarded information. So that's something that is not talked about in public. That's (indistinct) a general overview when you look at what you're trying to protect, and that's the top of the reactor vessel and everything below that. Again, PRISM is 50 feet below grade and it would be difficult to imagine how aircraft impact of, say, a commercial airplane would be able to affect that facility. So that's about as far as I can go down that trail.

MR JACOBI: Okay. Now, in terms of the fuel used, we picked up the notion that there's a metallic fuel that's used, and I'm just interested to draw out the distinction between metallic fuel that's used in this particular reactor and something that's otherwise known as metal oxide fuel that's used in other conventional light-water reactors. Are they the same thing or are they different?

DR LOEWEN: They're different. So nuclear reactors run on fissile material. Fissile materials can usually either be uranium or plutonium. In the case of

PRISM, it has a wider spectrum to use uranium, neptunium, plutonium, and americium. Rather than nuclear (indistinct) we went down the path of using oxide fuel, because oxide fuel is very stable under irradiation, meaning that if - the longer it's in the reactor generating heat, its dimension doesn't necessarily change because of increased use or increased power production.

With metallic fuel in a sodium-cooled reactor, the metallic fuel we use is more robust because we have the ability to control the diameter of the fuel, and we add sodium inside of the fuel pin, and that gives us good thermal bonding between that and the reactor, and we can get performance that's four times higher than what conventional oxide fuel can run at in a water-cooled reactor. So what that means from a performance standpoint is it can run longer and extract more energy from the material that’s inside the reactor to generate electricity.

MR JACOBI: I wanted to pick up that point with respect to the efficiency and the extent to which energy can be drawn from the same amount of fuel. I'm wondering about whether that can be expressed in terms relative to the fuel that's used in a conventional light water reactor.

DR LOEWEN: So we (indistinct) two different ways. One is the fuel efficiency of a water-cooled reactor can typically only extract 1 per cent of the available energy that's in uranium. If you look at PRISM, coupled with our advanced recycling centre, we can approach 99 per cent of the energy that's inside that uranium atom. So we look at new technologies, would you want to buy a car that gets one gallon per mile, or would you want a car that gets 99? So that's where this advanced technology extracts close to 99 per cent of the available energy out of uranium.

Now, when you look at steam cycle efficiency, that's another way to gauge a power system. A PRISM reactor has a steam cycle efficiency approaching 39 per cent, so it's similar to gas turbines combined cycles where a conventional water-cooled reactor has a steam cycle efficiency of about 33 per cent, and that's just because of the second law of thermodynamics. We operate at a little bit higher temperature, and with a higher temperature, we're able to extract more energy in the cycle.

MR JACOBI: Now, in terms of being able to use spent fuel within the PRISM reactor, I'm just interested whether you can offer an explanation as to the extent to which fabrication activity needs to be undertaken prior to that metallic fuel being used and what the nature of that process is.

DR LOEWEN: Yes. So the next item shows kind of a cycle where we take the used nuclear fuel that comes from water-cooled reactors. It's in an oxide form, and that's chopped up, and then we change that oxide fuel into a metal by taking away the oxygen.

Once we have that oxygen taken away, then that metal then - because there's so much uranium inside of used nuclear fuel, like 95 per cent, we pull some of that uranium out, and then four per cent of the mass is the waste that's inside of used fuel, which is the smaller elements such as krypton, rubidium, caesium, those sort of things that are put in a pile for disposal, and the we have - what we're after is the transuranics, which is about one weight per cent, and those are the elements of uranium and the ones that are bigger that uranium, neptunium, americium, curium and plutonium.

Those then are reconstituted into a fuel, and in round numbers it's about 30 per cent transuranics, 10 per cent of a metal called draconium, and then the rest is uranium. So that's a proven metal alloy that performs very well inside a sodium-cooled reactor.

MR JACOBI: Now, in terms of that fabrication technique, would it be necessary if one was to operate a PRISM reactor to have a fabrication facility associated with it? Or are there existing fabrication facilities that would be capable of manufacturing those particular fuels?

DR LOEWEN: Currently in the world there's no commercial metallic fuel fabrication facility in the world. So to use a PRISM reactor with an advanced recycling centre in Australia, you would need to develop that metal fuel fabrication treatment building. As (indistinct) Hitachi Nuclear Energy, we have a subsidiary called Global Nuclear Fuels, and they fabricate oxide fuel. So we fully understand the processes and the quality control to fabricate oxide fuels. I will tell you that it's a difficult process. There's a lot of parameters you have to control, it's hard to do, you have to run furnaces at high temperature because you have to centre ceramic. So think of it to make it a very high end porcelain object with very, very strict tolerances.

What's different about metallic fuel, it's very, very easy to make metallic fuel. You add the ingredients into an inductably heated crucible, which is a very easy technology. It melts, and then you pour that into a casting, and then you're done with your fuel fabrication. So this is the simplicity of using metallic fuel in a sodium-cooled reactor.

MR JACOBI: Are you able to offer any - I'm only asking in broad terms. If one was to operate one of these twin reactors at full capacity for a year, what the fuel load requirements would be to operate such a reactor on an annual average?

DR LOEWEN: I have the numbers. So for a PRISM reactor for one of those, to get it to start up you would have to go - you would have to consume

1000 tonnes of used nuclear fuel, and that will start up that power block that we've previously talked about, and then to keep it going over the course of its lifetime of the 60 years would consume another 1000 tonnes of used nuclear fuel. So if you help me with dividing 1000 by 60, it's - I don't want to get my numbers wrong, so that would be the number.

MR JACOBI: That's fine. The - I think the slide picks up the notion that there would be used PRISM fuel. We're interested in the waste products that would be generated by using a PRISM reactor. Could you explain what the nature of those waste products are, and the ability to either then use the fuel, or reuse the fuel, or generate waste, or the extent to which waste is generated?

DR LOEWEN: PRISM, just like a water-cooled reactor when it's at power and does the fission process, it breaks big atoms in half. Uranium, neptunium, plutonium, americium. When it breaks it in half, it gets into 778 different isotopes of what we call. The other terms for that is called fission products. So a PRISM we can operate a lot longer to a higher level of consuming those, and when - in the end, in round numbers, we'll have 10 per cent of the mass is those small elements called fission products. Those can no longer be used to generate fission energy.

They do have radioactive heat. So what the process does is pulls those out, and we put those into a synthesised rock, in an alloy, and then what I need to do is replace the cladding that's around the fuel pin, because it's worn out, and that puts some more material that will fission from the used nuclear fuel, and I start the process again. So its continuously recycling. So it would be very similar in the old days when we had the milkman deliver milk to our house in a glass bottle. When you ask how many times can you recycle a glass bottle, you can do it an infinite amount of times because you clean it back out again.

So PRISM becomes this - after it goes - the used fuel from PRISM, we pull out the things that no longer will fission or make energy, we add some more of those back in, then we stick it back in the reactor again. So now you have a system that's very similar to a biological system that continuously operates, so we have to add a little bit of fuel, and we pull the waste products out. So it would be similar to a human body where you're pulling poisons out of your bloodstream, and then you add in some more carbohydrates to get going.

MR JACOBI: Again, in terms of volume, in terms of the waste products that are produces, we talked about across the lifetime of the plant, using about 2000 tonnes of used nuclear fuel. What are the volumes of waste that would be generated by operating such a plant?

DR LOEWEN: I get nervous when people talk about volumes, because I can concentrate the waste form very, very small, into a very, very small waste form, but it generates a huge amount of heat. So we look at what do we do with that particular waste form, if it's very, very small and generate a lot of heat then you have to have external cooling. If you choose to put that waste form in to a geological repository, if it causes that geological rock to be greater than about 100 C then we start changing the characteristics of the surrounding that it' in. Now one of the things that we no longer look at but if you wanted to make something very, very small then deep sea bed disposal removes that heat but we're not going to do that. So what we have decided as a community, if you look at the National Academy of Sciences from Russia to the United States, the European Union is we're going to use deep geological repositories. So what you want to look at then for a deep geological repository is the requirements for that heat dissipation. What is unique about PRISM waste is that it's radioactive to a level for about 300 years, or if we look at current usage of fuel, you have to worry about that heat on the order of 100 to 200,000 years. So that is the advantage of PRISM is we get elements that are more radioactive, they will decay faster, that heat dissipates quite quickly and then after about 300 years, it's less radioactive than the uranium ore that you dig up in Australia.

MR JACOBI: Can I just pick up on that? Could you explain what the constituents are of that waste that are radioactive? What are the radioactive elements?

DR LOEWEN: As I said, when you break uranium in half or plutonium, our codes show that there is 778 different isotopes. So if you remember the periodic table of elements in chemistry, which were – you pick 82 elements, imagine all the different isotopes, they have over 700 of those. So you almost have pretty much every element that's on the periodic table to some concentration. And when you design it in our (indistinct) form, I would say Australia was a leader in the early nineties, or in the late eighties or early nineties when they looked at the development of synd rock or synd and they had different synd rock, A, B, C had different recipes, our waste (indistinct) would be very similar to that. We don't do a hot isostatic press but we put those elements, if you remember your chemistry of group 1 and group 2 and the halogens, we combine those together, very similar to what nature does, to make a mineral and then those elements that are in the spent such as noble metals that typically can be found in nature as a metal, we mix those in alloy and iron and zirconium and then that becomes a stable matrix in the ground. So in the end, the waste would be an engineering ceramic, similar to synd rock and a metallic alloy that's major constituents are zirconium and iron.

MR JACOBI: If I could move on from the issues of the waste and come back to, I think where the commissioner started, and that is I am just interested to understand – I think you made reference in your first answer to the difference between this particular sodium cooled reactor and other sodium reactors that are operating elsewhere. I am just interested to understand the development pathway to the development of PRISM by GE and then to understand a little bit about the differences between it and other sodium reactors that are operating elsewhere in the world, or have otherwise been operated?

DR LOEWEN: Well the development pathway for PRISM started in 1981. At the time the United States was in the development of a large sodium cooled reactor called Clinch River breeder reactor project. We were not the prime contractor or technology provider for that project and we realised they're going very, very big with sodium cooled reactors wasn't in the best interest of safety, performance and economics. So as a company we said, we're very good at making things in a factory because we can control quality, we can control cost and we can control schedule. And from that, you can see from slide five, kind of how are development went. That one that you have in front of you - - -

MR JACOBI: Yes, I do. Yes.

DR LOEWEN: We set off to do something different. We say how do you make a factory built reactor and what are the parameters to make it safe. So that's how the development went. It was funded by the US government and it was also an international programme, as I said before, from 1984 to about 1994. So while I think it's germane to what we – what you as a commission are looking at for Australia is how do you pick that up and leverage the hundreds of millions of dollars that were spent by US taxpayers to deploy the technology to put you in a different sort of marketplace. So one of the ways that would be – to do that is one approach is similar to what the United States did for the Apollo space programme. The very first Apollo rocket that was built, they knew it wasn't going to fly to the moon but they needed to exercise the supply chain early and they needed to measure some big things such as the vibrational frequency. We propose the same thing for PRISM. We would build a facility that would be at scale, that would exercise the supply chain in Australia, it would use the people that would be a part of this project in Australia but it would never function as an operation reactor. We would use water and we would use that, one to help shape down the design as we go through the licensing process, it would make a regulatory body comfortable with the approach and then once the facility is operational then we would have the ability to continue to train operators for when they're on the PRISM reactor.

This is exactly what we do with our boiling water reactors. We have a facility in San Jose that is a replica of a boiling water reactor number 6. We use it, our customers use it and that's a place – from a licensing standpoint, you just have to worry about occupational safety of a large body of water and structural sort of things, you're not dealing with any radioactive materials. So that's how we could see we could start earlier in Australia with this technology, as you grapple with where you want to take the study as a commission.

MR JACOBI: Just to pick up on the second question that I asked there which is, are there reasons for thinking that this reactor is likely to have different results than other fast reactor projects. We've heard in submissions, a little about France's attempts with its Super Phoenix. We've heard a little bit about Russian sodium cooled reactors. Is there key differences with the GE PRISM design that you'd like to draw our attention to?

DR LOEWEN: So they key features why our technology is better and why our technology is more economic and safe is it comes down to one thing, it's metallic fuel. And it seems so easy, or why is that such a differentiator. It comes down to this metallic fuel and the United States is the only country that had this experience with metallic fuel, so it makes the fabrication of the fuel easier, the safety performance easier and when we look at the operation that is what is going to make it more economic. And if you look at programmes in China, India and – well, I will leave it at those two because I've seen there – they want to head to metal fuel because they know that's where the best performance is and so that's what's unique about it. That experience came from the United States, the very first reactor to ever make electricity was EBR-1 using metallic fuel and that was followed by experimental breeder reactor number 2 that operated for 30 years. Again, using metallic fuel or had the test base.

Also what's different about PRISM is back when we talk about the loss of cooling accident all of the primary system is inside of one vessel. There are no pipes and there's no valves external to it; that gives you a very robust safety case that a (indistinct) vessel surrounded by another vessel, in a silo that we saw in that other picture, lined with stainless steel and through those three barriers, we as a designer said we don't have a loss of cooling and the Nuclear Regulatory Commission during their nine year review of the technology from 1987 to 1994, also agrees that a loss of cooling accident for PRISM is done. So if I had to put it in two things, it's because we're metallic fuel and we have a pool type sodium cooled reactor.

COMMISSIONER: Could I just continue that discussion? We went to Japan to Monju and had a look at that reactor and certainly what appeared to be a reasonably small sodium leak had a disproportionate impact on the availability of the reactor. What lessons were learnt from that particular activity and why should we not be concerned that that won't also be a feature of PRISM?

DR LOEWEN: PRISM has incorporated the experience of the 22 sodium cooled reactors that have operated around the world; Monju is one of them, as you pointed out. Monju had a – as you pointed out, a very small sodium leak because one of the thermal couples they didn't follow the standards in the case that it caused (indistinct) induced vibration and broke and that led to a leak. What was unfortunate was that the leak was detected and was ignored and that leak continued for hours and that leak resulted in interaction of the sodium with the concrete.

The PRISM design, again, with our primary system, we - and the Nuclear Regulatory Commission agrees - we cannot have a leak. In our secondary system, the intermediate transport loop, what we've done there is we have double concentric pipes where the sodium is in the centre pipe. Then we have leak detectors and then a secondary pipe around that to mitigate the possibilities of having a sodium leak.

MR JACOBI: Can I just pick up on the aspect of the history of the technological development. I'm just interested to understand whether you have any perspective on why, in essence, light-water reactors have become the dominant technology and that fast reactors haven't been used more widely commercially over perhaps the last two decades.

DR LOEWEN: I'll do a little bit of history if you don’t mind. So if you look at post World War 2, you had a lot of people that worked on the Manhattan Project. I've had the opportunity to have two of those people as close friends, and what they shared after the close of World War 2 was they didn't see the ability to do the peaceful uses of this technology because they saw uranium as a very limited resource. They weren't aware of the vast amounts of uranium that you had in Australia. So the very first reactor that was built was experimental beta reactor number 2 and that was we need to generate fuel in these reactors because we don’t have enough to make this technology a peaceful use rather than the military use that it was initially derived for.

What happened then, as I jokingly say, is that then the grocery store started selling Geiger meter counters and people started prospecting for uranium. So the town where I grew up in, the town I went to college in, had uranium mines and metal tailings in Colorado. Canada started finding vast reserves of uranium and Australia vast reserves of it. So it became easier to say, "All right. Let's just dig it out of the ground with a very, very low concentration. We'll do some enrichment. We fabricated the fuel and put it through reactors. So this commodity became very cheap and that took the emphasis away of approaching technology different.

So I don’t come before you today saying that we're going to run out of uranium and we're resource limited. What I say to you is you have a big business opportunity in southern Australia because there's a lot of used fuel around the world. So in round numbers it's like 160,000 metric tonnes. All those nations are grappling with, "What do we do with it?" So PRISM provides the technology used in a sodium-cooled reactor to turn that waste into lots, and that's where we at GE imagine things differently. We're technology innovators. That's where we see great opportunity to bring this technology forward.

MR JACOBI: Can I come to two particular technical aspects of the plant? The first is to the issue of heat removal, and I think we might have a slide that picks up heat removal - - -

DR LOEWEN: The easiest slide to see the heat removal is slide number 9.

MR JACOBI: Now, I'm just interested in understanding - and there are particular rights to issues of water use - the extent to which it can use air cooling or might be suited to air cooling.

DR LOEWEN: Okay. What's shown on the slide is how PRISM uses air cooling to remove heat from the reactor not measured in hours or days or weeks but forever. So we look at the fundamentals of reactor safety of any nuclear power system. You have two basic things: one is how you control that reactor when it's at power; and the other one is how do you remove the heat from that reactor after you've shut it down. So in the case of Chernobyl, that reactor was not controlled well when it was at power and that resulted in generating three times its rated thermal power resulting in the explosion.

If you look at the case of Three Mile Island and the case of Fukushima, both of reactors were shut down safely. They were sub-critical but because nuclear power is different that some of that radioactivity causes heat, initially at 7 per cent, then after 24 hours it's at 1 per cent, if you don’t remove that heat it'll result in core damage. PRISM recognise that. PRISM said, "How do we it differently, and how do we do it so it's not dependent on pumps and valves and electricity?"

So you can see at the very top is a vent that takes air, and we can use hot air in the summer or cold air in the wintertime, and it comes down, way down low, underneath the reactor vessel. Then hot air rises as it's beside the reactor vessel and that hot air goes out the top of the stack. So normally when this system is running it loses about 1 megawatt thermal energy. So I will take that penalty in performance because then I can say to any member of the public, "My system is always removing that heat."

Now, when we get into an accident scenario where the sodium inside that reactor vessel heats up, it swells because of the heat and that produces a natural circulation inside the reactor vessel, and that natural circulation causes the natural circulation outside in the air to not remove 1 megawatt thermal energy but 9 megawatts thermal energy, and that's how the PRISM reactor has the ability to remove that heat. Initially after the reactor is shut down and then as it tails out that heat decreases, then it doesn't work as hard. So that's the beautiful simplicity of this reactor system. So we constantly try to improve reactor systems and so a PRISM reactor does that wonderful thing: "I don't need to have water."

MR JACOBI: If we can go to the circumstances of a complete loss of power, and that is a complete loss of AC and DC power such as occurred at Fukushima, I'm just interested to understand how the plant works its way to being effectively shut down in that event. Does that require active intervention? How does that process work?

DR LOEWEN: For the PRISM reactor we have nine control rods up on top and they're held up out of the reactor core with electricity and that's the motor that moves it. In the event of a loss of all electrical energy on the site, that would cause those fuel rods or control rods to release and fall in by gravity, and there is also a spring that assists them. So once those control rods are in the reactor goes to critical. So in the case of PRISM, we have nine rods. We only two to three to go in, so we actually have extras because we need to control the neutrons all the way across the reactor core. So I don't need all of them to go in.

So now that the reactor is turned off so the fission process has stopped, I still have heat to remove, and the previous system that I described of removing that heat with the laws of physics where the cold air comes down, relatively cold air from the outside, and you have the hot air comes up, sets up a natural way to remove that heat not measured in hours, days, but forever.

MR JACOBI: Now, just picking up on I think an issue raised by the Commissioner with respect to the interactions between sodium and air or sodium and water, I'm just interested to understand how that particular risk is managed within the PRISM system.

DR LOEWEN: So it is a chemical hazard and that's who we have to look at it. So in society there's a lot of chemicals that we use in bulk that we need to be cautious of. For example, we use chlorine to clean the water of our cities, we use ammonia to fertilise our fields and farmlands, and with sodium it's no different than a chemical hazard. So it is true that we have sodium that comes out in air. It does oxidise and if there's moisture you will get a fire, but I would tell you that a sodium fire of metal spilled onto a metal surface, though it burns, is not like spilling a petroleum product as far as a rapid fire that occurs.

I'm not saying that it doesn't occur, but I'm saying if you took - pound for pound, I would take a pound of liquid sodium on the ground before I take a pound of gasoline on the ground from a safety standpoint. So that's when we look at sodium in air. The next one you mentioned is what happens when you mix sodium and water. So if you look at slide number 8, the way we convert that energy from the fission reactor, that heat energy, to make power is we make steam. So in the centre of that we have a device called a steam generator. So we have coils that are wrapped around where the water flows in, and that water goes from steam - from water, to steam, so superheated steam, and comes out and goes to the right-hand side to an electric generator. So the question is what happens if one of those tubes break? That's when you get a reaction between the water and the sodium, and that results in the formation of sodium hydroxide or sodium oxide producing hydrogen gas.

So the - we have learned from the studies that were don in Japan on two breaks of water tubes, what happened in the UK at the Dounreay reactor is we have a PRISM system that has four different ways to check for a small leak before it breaks, and then if you have a catastrophic break of those tubes of water, we have a rupture disc on top that relieves the pressure, so it doesn't require electricity to do that, and the shell of that grey thing is designed to be able to hold that pressure until you start removing the sodium. So even in that worse case, this plant can rude through better because of the teachings of the other plants if a tube breaks inside the steam generator.

MR JACOBI: I'm just interested to perhaps move on to deal with issues of the extent to which the technology has been demonstrated. I understand that the PRISM design is built upon the EBR-II design, and I'm just interested to understand the extent to which that means that parts or components of the technology within PRISM have in fact been demonstrated to operate. Demonstrated in their operation.

DR LOEWEN: So PRISM benefited greatly from the 30 years of safe operation of the Experimental Breeder Reactor II. We also benefited from the ten years of the advanced liquid Metal reactor program that ran from 1984 to 1994 where large components and questions were tested. So the case of the steam generator that I just got done explaining, a steam generator was operated at a facility in California to test the design that's our baseline design for PRISM. One of the other unique features of PRISM is you use electromagnetic pumps.

Those pumps have no moving parts inside of them, rather we use electric fields and magnetic fields to cause the sodium to flow. The world's larges pump was tested with a company - a company in Japan built half of it, we built half of it, that again came together at a test facility in California where those components were tested. The seismic isolation bearings that we were going to use are unique. This will be the first nuclear facility to use those.

We're going to build off the experience from the civil engineers that use those in buildings in Los Angeles, and in Tokyo. What else did we - a digital control system. PRISM was GE Hitachi's first digital plant. So we came up with a concept that was very robust in 1981, and it's not until now that we're using digital technology in our two products called advanced boiling water reactor, and our ESBWR. We're going to benefit from those reactor systems going forward, and get in their slipstream, if you will, and use a very similar sort of digital system that has enveloped all the different world requirements when it comes to cyber security, diversity, determinacy, redundancy and independence.

MR JACOBI: Are there - just moving away from the aspects that have been tested, I think you've described a number of aspects that are different from EBR-II and build upon lessons from other reactor types. To what extent - are you able to express a view as to the extent to which PRISM depends upon novel concepts? Then I'm interested to understand the extent to which they've been validated.

DR LOEWEN: I'm not aware of any novel concepts. That's where we have a firm foundation of metallic fuel that comes from EBR-II. Others would call that novel, I don't. I consider 30 years of operation EBR-II sound. Electromagnetic pumps, my competitors say that is novel. I don't consider it novel because GE back in 1954 built a nuclear submarine for the US Navy that was sodium cooled where we built electromagnetic pumps. In fact we had a business in the 70s and 80s where we manufactured and you could buy electromagnetic pumps from GE, so I don't consider those novel.

When you look at a steam generator, which we call a helical coil steam generator, I don't see that as novel because if I look at the new small modular reactor designs that are out there that are water-cooled, they're using helical coil steam generators. When we look at our steam turbine, we're using superheated steam, I don't consider that novel because GE Power and Water uses gas turbines coupled to a steam plant, they use superheated steam as combined cycle.

But there is a lot of robustness in the design when the engineers that have worked for me - a lot of robustness for the design that started in 1981, and when some of my engineers come up to me and want to do novel things like supercritical carbon dioxide or some of these other things, I say, "Let's sell the first 10 PRISMs, and then we can do these other sort of things. Let's do thorium fuel, let's do supercritical carbon dioxide," those sort of things.

So we are presenting what is a very robust design basis for the PRISM reactor that's leveraged again, the 22 operating reactors of sodium, some of which haven't had the best history. So that's why we as a technology company want to be thought leaders, and leaders in this new space as far as imagining things that can be different with the nuclear fuel cycle.

MR JACOBI: Can I move on to deal with proliferation and nonproliferation aspects associated with PRISM? The Commission has received many submissions that are concerned with nonproliferation. I'm just interested to the extent to which GE has a view about whether there are proliferation - there might be nonproliferation advantages or disadvantages associated with the PRISM reactor and the processing technology.

DR LOEWEN: So as a US based reactor vendor, we have to follow the laws of the US government as far as export of reactor technologies. What we are - so the PRISM reactor that we can offer Australia is a proliferation resistant - has proliferation resistance. I've been warned not use "resistance" because some of the people in that field say nothing is resistant, but it has resistance in the case that it consumes more fuel than it produces.

So there are concerns that a sodium-cooled reactor can be turned into a breeder reactor. For the PRISM reactor, what we - the processing technology that we're offering is proliferation resistant. To change it to (indistinct) operating would take a significant amount of effort, and is easily detectable.

MR JACOBI: The - - -

DR LOEWEN: That's as far as the reactor goes. I'm sorry.

MR JACOBI: This is the issue I was raising. I think there's a suggestion in the submissions that such reactors are - I think the expression that was used was "breeder capable", and I'm just interested in understanding what the technical challenges would be for someone that was - you expressed the view that it would be difficult to make the modifications. I just wonder whether you could expand on that.

DR LOEWEN: Firstly, for the record all water - all reactors produce plutonium if you're using uranium as your fertile material. If you go to a thorium-based system, you're producing uranium-233. So when you deal with reactor technologies, you need to be aware of the system response when it's operating. So PRISM is aware of that. So we worked with the Department of Energy in the design of PRISM that we can offer worldwide to where we don't produce more fuel inside the reactor core.

So that's where you make the core size smaller, you change the way you put the fuel in there, you're not using blankets, so you're doing those sort of things that can be easily validated by the IAEA, because I assume that Australia is going to use those as kind of the guidelines. It's very easy to be able to see. So PRISM doesn't have as many fuel bundles, it's very easy to see fuel movements, and we use a welded seal so you can make sure there isn't tampering. So we feel that PRISM is very robust when it comes to proliferation resistance. I'd be proud to put it up to any sort of thing, so I think it's a very resistant technology.

MR JACOBI: Perhaps moving away from the reactor itself, and moving towards the processing technology, I'm just interested to understand whether GE has a view with respect to its resistance or proliferation resistance in particular.

DR LOEWEN: I'm sorry, with the separations?

MR JACOBI: Yes.

DR LOEWEN: Okay. So the advanced recycling centre is coupling two different technologies, a PRISM reactor and electrochemistry. So electro-chemistry is used in metallurgical processes such as producing aluminium or titanium. That separation process one has to add electricity to get it to separate in to the constituents. So the PRISM technology is using a chloride based salt and which a chloride based salt, when you apply a voltage to the separation of uranium, neptunium, plutonium, americium, they all pretty much come up at the same voltage. So if there’s malice intent, it’s impossible to separate those elements. Now there are other salt systems that I won’t mention, to where you could have that sort of separation because the chemistry allows it. So again, it’s very easy from a proliferation standpoint to make sure that our chemistry is done in a chloride-based salt. It’s easier to tell those other salts, you can easily - detectors and for IAA inspector to see if there was malice.

So because of that, when we look at the signature of materials of concern, we always wonder can it be detected. So in the case of PRISM fuel, it has a very good signature in the case that it gives off a strong radiation dose of both gamma rays and neutrons towards easily detected, as compared to if you had pure plutonium 239. It doesn’t give off much radiation and it doesn’t give off much neutrons, so it’s hard to detect. Again with PRISM fuel, it gives off a lot of gamma rays and gives off neutrons, very easy to detect. Another issue is with that sort of fuel, how much heat that is produced and do you have to have active cooling? And so again, that’s with the PRISM fuel produce a lot of thermal energy and again, that makes that detection to be able to see it. So that is why we are very confident that this is the next generation, the way to do chemistry. We’re not relying on assets or bases. If you want to turn off the chemistry, you turn off the electricity. So if you have a loss of power, a loss of electricity, the separation process stops.

MR JACOBI: Can I come to just deal with some issues of economics and I am just wondering about whether it’s possible at this stage to express any views about the ranges of costs associated with respect to the development of the PRISM reactor that we’ve been discussing?

DR LOEWEN: So as you can imagine, as a shareholder owned company that costs are a sensitive nature but I think to help the Commission with some ranges, the Department of Energy looked at a PRISM like facility, or a PRISM like reactor in a 2000 report. I would caution to read – I would caution you from looking at the numbers in the front of the report but if you look at appendix B, they came up with a cost of a PRISM reactor facility of about six billion dollars and we would describe that cost as very reasonable. If you look at that same appendix, where they looked at the cost of a fuel fabrication facility, which would be needed for PRISM, they came up with a cost of about three billion dollars. I was aware of Senator Edwards' work, his report. He came up with a number that was about 455 billion and so we believe the cost is between those two. So I hope that helps give you a range for the Commission.

MR JACOBI: I am just interested, given GE's experience in deploying reactor technology elsewhere in the world and not particularly the PRISM technology but I have in mind the ABWR technology, about the extent to which those costs are, or the ability to sight those costs and the extent to which they are dependent on the location of, or the place of construction?

DR LOEWEN: The prices – so price of a nuclear power plant – so it does, the bottom line. One of the things is where's the concrete going to come from in that infrastructure to be able to do that. So that's a cost driver. Then you look at your labour pool, so other reactor – or other countries where there's deficiency in the craft labour, you can see that you have to import those, that's going to add to the cost. So the experience that we had with the advanced boiling water reactor in Japan is we did all of the design beforehand, before we started. The reactor was put in to modules, so to be able to make modules, you have to know where all the light switches and the plug ins and all those sort of things are going to be and then stuck to a schedule. So the very first plant was built in 36, 39 months. Second was 44, so they kept with that cost of schedule. So when you look at big capital intensive projects and what the customer like you would need is cost certainty and schedule certainty, my advice would be, do a lot of that early engineering work and make those decisions early on, on how you are going to divide up the scope so that you can have a schedule you can meet to and you know what the costs are going to be.

COMMISSIONER: Dr Loewen could you just tell me what years those two reactors were built?

DR LOEWEN: They were K6 and K7 and they came online in 1996, 97, 1997.

COMMISSIONER: Thank you.

MR JACOBI: You have referred, in the answer you have just given, to the ability to build plants in modules and I am just interested in the extent to which the – it's proposed that the PRISM reactor can be constructed or manufactured in a factory as opposed to – and then essentially assembled on site as opposed to what has been described to the Commission as being stick built, in the way that LWRs are?

DR LOEWEN: That's how the PRISM reactor was conceived in 1981, to be able to make it in a factor and make it rail shippable. The reactor got a little bit bigger and so we are no longer rail shippable but it can be shipped down the road if you buy what we call PRISM mod A. This - we had the ability to have great automation is when you start making it in to the factory and then you ship it to site. You're still going to have to pour concrete, you're still going to have to excavate because as we sad before, or as I said before, we're below grade but the more of those components you can build in a factor, and so we did that with the ABWR. PRISM lends itself – it's a lot smaller and so the ability to modulise different components, so we've done a modulisation study on the different modules that would be factory built and then assembled on site. So that's a tough call. If you are doing just one PRISM power block or a couple, is it worthwhile to build a factory then you don't sell any. If you were looking at doing more, it's tough. So when you look at the aircraft industry, which the PRISM team did study, it's tough on how many of those – you know, what's a break-even point to where you go from stick built to that factory built? And so that is – again, you'd have to look at business model.

MR JACOBI: I'm sorry. Just to come back to the – you referred in an answer, and I understand the sensitivity of asking a question about cost but you referred in an answer to a figure of six billion dollars from a DOE report in 2000 and I think you expressed a view as to – I am just interested to understand whether you thought that that was a reasonable estimate then or it remains a reasonable estimate now given the 15 years that have elapsed between the two? Between the estimate and today?

DR LOEWEN: I'm sorry, what I meant to say that that study was done in 2014 - - -

MR JACOBI: Sorry.

DR LOEWEN: So it's only a year old. That study was done for the disposition of plutonium in Savannah River which is not too far from where I live in Wilmington, North Carolina and the cost that they came up with, again I need you to look at appendix B. So I'm not endorsing anything that's in the front of that report.

MR JACOBI: Okay.

DR LOEWEN: So what I’m saying is if you look at appendix B, the cost of a PRISM power block that we’ve talked about and we’ve had on the screen is about six billion dollars, so based on what they’ve done, we would say that’s reasonable.

MR JACOBI: Sorry, again, look this might be my misunderstanding, did you – was that a single power block or was that both – or is that two reactors?

DR LOEWEN: So it’s a power block which includes two reactors.

MR JACOBI: Right.

DR LOEWEN: And one is steam turbine.

MR JACOBI: Thank you. Sorry.

DR LOEWEN: Now that six billion is back to the conundrum of nuclear power; it includes all the First-of-a-Kind class of regulatory, all the First-of-a-Kind class in design, and that was for a single-emission disposition 33 metric tonnes of plutonium to be in accordance with the treaty that we had with Russia. So we won't get that number. I would ask you to look at it in that light as far as where that number came from, because the Department of Energy was saying, "All right. How much would it cost to build this?" compared to other options that they were looking at at the time.

MR JACOBI: Picking up from this question of economics, I'm just wondering about whether or not GE has published any information concerning the broad range of LCOE's that expects. We've heard from other vendors expressing views in terms of the levelised cost of electricity. I'm just interested as to whether GE has published any information with respect to its view as to what the likely cost of energy would be as generated.

DR LOEWEN: We typically don’t publish those because that's not us. We're the reactor vendor that provides a technology and it's really the utility that has to look on how they're going to finance, what sort of take-offs they'd have. But I would ask the Commission to think about the broader mission of PRISM. It produces electricity as a side benefit. You have the ability now to have people pay you, or countries pay you, to take their used nuclear fuel. You use this technology to what they consider waste into lots, and then the side benefit is you cover your operations by selling electricity. We see a different future for the fuel cycle. That's why we're excited about this technology in Australia and in other places.

MR JACOBI: Perhaps if we can deal with the issue of licencing in a little more detail than we have. I read in some of the documentation references to a design concept document, and I'm just interested to understand where GE sees this particular technology in terms of its ability to be licenced and the work that would need to be done for it to be licenced.

DR LOEWEN: So one slide to take a look at would be slide number 15. To quickly answer your question, I would say that this reactor is licensable and can be licenced. So I had the opportunity, 1 September this year, 1st and 2nd, to participate in a workshop between the Nuclear Regulatory Commission and the Department of Energy. The Nuclear Regulatory Commission recognised that the licencing review that was done on PRISM from 1987 to 1994 was robust, it was the real thing, and that the plant is licensable. Again, there are a lot of things that we needed to do as far as code cases and different things and were ready to be able to do that. So that should give confidence that it's had a formal review from the Nuclear Regulatory Commission.

We look at how it will be licenced or how would you do that in Australia. I would suggest that you have the opportunity. You have a clean slate. We see in the United States we have a regulation that is very proscriptive because it grew up with one technology: that was water-cooled reactors. When I look at the United Kingdom they had a diversity of technologies they used of gas-cooled reactors, sodium-cooled reactors, water-cooled reactors, reactors that were out at sea in the military complex. Well, they used more the evidence-based approach. So we had these safety analysis principles. You make some claims and you provide the evidence to do that.

So what we recommend is a less proscriptive sort of way. You have a unique opportunity that you could go in, "We're going to take this particular title from this country. We're going to adopt all these IAEA standards," and then as you look at a project to be built in your country you could see, "You need to follow these standards." So it's nothing different than a vendor that's providing an electrical component that has to follow different standards. They have to provide you the evidence that it does that.

So what I want to give you is hope that you don’t have to stand up your own regulatory agency, be very similar to a country that's entering for the very first time commercial airlines and they need to set up that same sort of infrastructure to buy a plane, to train their pilots. If they adopt all the safety rules I would feel safe flying in those sort of planes. So that's why I suggest the Commission look at some options as far as being licensable. But back to answering your question again, definitely licensable. The NRC said it themselves. There's a document you could read called New Reg 1368. I didn't provide where they made that statement.

MR JACOBI: Perhaps if we look at the UK. The Commission understands that what you described is, I think, sometimes expressed there in terms of being an outcome-based approach as opposed to the system that's used in the United States. Does GE have a view about the sort of time frame that would be required were it to seek to licence prism in the United Kingdom? Does it have a view about the sort of range of time that it might take to licence under that existing regulatory framework?

DR LOEWEN: Let me give you two reports that you can kind of reference. If you look at again that 2000 report by the Department of Energy. Appendix B, they assumed that the range would be 15 years based on US licencing. If you look at the report that Sean Edwards did, he said that was ten years. I like his ambition. If you look at the advanced (indistinct) the United States and water-cooled reactor, that took us ten years in the United States. If you looked at our ESBWR, that was about nine years to get the licencing. If you look at the Office of Nuclear Regulation, the reactors of some competitive technology, that was on the order of six to seven years. Unfortunately it's measured in years. I think if you adopt the right sort of processes there's no reason why it can't - you can for sure make it less than a decade.

MR JACOBI: Can I just come last of all to a view about where GE sees that there might be markets for PRISM to emerge? Does it see that the United States is a prospective market in which the PRISM technology might emerge and be constructed in a First-of-a-Kind process?

DR LOEWEN: So when you look at markets you have to have the policy framework in the country. The policy framework that got established in my country was established in 1982 as the Waste Policy Act that essentially said that used nuclear fuel is the property of the government and you, the utilities, pay a flat tax. That process continued in 1987 where we picked one State to be able to put that waste, which has probably become fairly famous, called Yucca Mountain, and that process has stopped. So there isn't the policy framework to commercialise this technology in the United States because if you're a utility that has used nuclear fuel there's no incentive to look at different approaches.

If you're a nuclear regulatory commission you're not looking at other metrics like how much transuranic am I going to put in the ground, what is my long-term heat generation rate, what is the leachability of this waste from what I put in the ground, is there any energy content. So that's why in the United States, unfortunately, we don’t see that policy framework. The light kind of got bright during the Global Nuclear Energy Partnership that started in 2006. The light got dim in 2009. It got a little bit dimmer after the Blue Ribbon Commission looked at it. So that's why we're looking at markets external to the United States that have used nuclear fuel and they're looking for solutions. They have that persistence and they want to be technology leaders.

MR JACOBI: Perhaps if I can go to the situation in the United Kingdom, and

I think we've got a slide that picks this up. I'm just interested to understand your view about the possibility that PRISM might be a developed option for the issues that they face in the UK.

DR LOEWEN: The United Kingdom separates civil plutonium and they store that in its - so that process operates (indistinct) and that operation completes according to their - the way I read their records, they'll have 140 metric tonnes of separated civil plutonium. So that plutonium is an oxide form. Some of that plutonium is very, very old. So it has ingrowth of an isotope called americium. Some of it has other sort of contaminants in it. So what we proposed was the same fuel fabrication process to make metallic fuel, which is easy to do, which is robust, and we would convert that plutonium oxide into PRISM fuel, and then we would take that fuel and use that to make some electricity.

Now, in the UK for their policy reasons, they don't want to do any recycling. So this is what we call plutonium disposition to where we make fuel, it runs in the reactor to a certain level and then that would be put into a deep geological repository.

COMMISSIONER: Dr Loewen, thank you very much for your evidence this morning. We very much appreciate your time.

DR LOEWEN: Thank you for having GE Hitachi Nuclear Energy provide you the information.

COMMISSIONER: Thank you.

MATTER ADJOURNED AT 9.09 AM ACCORDINGLY