COMMISSIONER: Good morning. We welcome to topic 16, High-Level Waste Storage and Disposal, from the US, Dr Thomas Cochran. Counsel.

MR JACOBI: Nuclear power generate produces a range of waste forms, including spent nuclear fuel. Spent fuel from nuclear reactors, however, possesses a range of properties that pose technical challenges for its management, storage and disposal that distinguish it from other lower-level nuclear radioactive waste. Most significantly, spent nuclear fuel is both intensely radioactive and heat generating. Spent fuel acquires those properties due to the fission reactions which occur during the operation of a nuclear reactor, which result in the production of other radioactive elements from the uranium fuel. In addition, elements in the fuel, which are not naturally radioactive, are irradiated and themselves become radioactive.

Though some of the products of the fission reactions are short lived, many are notify. They maintain their radioactivity, though they decline slowly, over significant timescales to be measured in the tens of thousands of years. Those characteristics have required the development of specialised techniques for long-term management and disposal of spent fuel. The public sessions on this topic will address a number of those techniques. One option which has been suggested is the recycling of that waste for its reuse as a fuel in so-called fast reactors. This type of reactor has already been addressed in the evidence of Dr Loewen and Dr Lyman before the Commission. The Commission has also received written submissions both advocating and opposing the further investigation of such facilities, and we return to this topic again briefly this morning.

A further option of reprocessing and disposing of the waste products from that process as intermediate level waste was addressed last week, particularly in the evidence of Mr Griffiths of ANSTO, and we'll also be addressing that topic this morning. An alternative is the direct disposal of spent fuel in geological repositories. This does not require the fuel itself being transformed before disposal. This technique will be examined in more detail today, particularly in the context of Finland's experience in the siting and proposed construction of a deep geological repository. Later this week, we will also hear from experts with experience with similar processes in both the UK and US.

It is important for the Commission to understand that technique and to understand the character of its barrier systems. It is crucial that the Commission understand the techniques used as part of the safety case for those proposed facilities, which are said to offer assurance that the spent fuel will not pose a risk to humans or to contaminate the environment over the relevant timescales. The Commission is also interested to understand the challenges in communicating such assurance to both relevant close communities and the general public.

The Commission calls Dr Thomas Cochran of the Natural Resources Defense Council. The NRDC is a large environmental action group based in the United States. It liaises with businesses, policy makers, and other community groups in relation to significant environmental issues, including sustainable energy generation, global warming, and protecting endangered fauna in their habitats. Having retired in 2011, Thomas Cochrane is a consultant to the NRDC. Previously, he was a senior scientist at the NRDC and, until 2007, was director of their nuclear program. He provides advice to both public and private bodies on matters including nuclear energy generation waste and non-proliferation.

Dr Cochran continues to serve as a member of the US Department of Energy's Nuclear Energy Advisory Committee and several of its subcommittees, including the Nuclear Reactor Technology Subcommittee, and the Commission calls Dr Thomas Cochran.

COMMISSIONER: Dr Cochran, thank you very much for joining us today. Might I start with a question in terms of the fast reactors? I'd like to explore the development of fast reactors concurrently with light-water reactors. What was in the mind of the developers for the fast reactor? Why were they developed concurrently?

DR COCHRAN: Well, the fast reactor development dates back, in the United States, to 1944 during the Manhattan Project, and some of the premier nuclear scientists that were working on the Manhattan Project in what is called the Metallurgical Laboratory in Chicago, which has since become Argonne National Laboratory, most of their work had moved out to Hanford and they were looking for what they might be doing after the war ended, and they decided they would get into the business of generating electricity for power, civil use, and at that time they thought uranium was scarce, which it turned out to be they were mistaken, but at the time, in 1944, it was indeed scarce, because very little had been produced, and so they knew from the previous year about the concept of breeding.

So they started exploring the concept of breeding plutonium and utilising more efficiently the uranium resource, namely, the more plentiful uranium-238. Now, the Met Lab became, after the war, Argonne National Laboratory and that became the centre in the United States for civilian nuclear power research and development, and so they continued to focus their attention the fast breeder reactor while in subsequent years the country developed, through the naval propulsion program, the light-water reactor concept. But being engineers, they were wedded to this concept of getting the most power, the most energy, out of a gram of uranium, which meant eventually going to a closed fuel cycle, breeding plutonium in the reactor, recycling the fuel, recovering the plutonium and putting it back in the reactor to refuel the reactor.

Now, there were about three major breeding concepts that were under development by the Atomic Energy Commission in the United States in the early period, and they eventually focused down on the liquid-metal, fast-breeder reactor as the most likely candidate, and that was in part because the hazards of R&D program had come out of the naval propulsion program (indistinct) in developing that reactor, which was eventually put into the second nuclear submarine, the Seawolf.

If you go back to the late 60s, early 70s, when the Atomic Energy Commission - this was their highest priority energy R&D program and because of the amount of money they were spending, it was also the highest priority energy R&D program in the entire US government, and in fact President Nixon went out to Hanford and gave a speech and said this was the best fast breeder reactor with the best hope of meeting the energy needs of the future. Well, in those days, they thought that as they were going to build a lot of reactors, like, 3,000 in the United States - they ran some cost benefit analyses projecting this huge development program, and because they were going to chew up the low-cost uranium reserves, uranium prices were going to increase and this was going to be (indistinct) the light-water reactor fuel very high and the breeder would be competitive.

Not only that, because they were going to build so many reactors they were going to be on sort of an industrial learning curve, and the cost of building the reactors in constant dollars was going to come down from about $150 a kilowatt to about $100 a kilowatt, and the small cost difference between a liquid-metal fast-breeder and a light-water reactor would also come down. So these were going to be very economical by about this period of time, by today certainly, but even before then. Now, there were a few flew flaws in their thinking, some because they didn't think of them and others they just had it wrong. First of all, the cost of uranium in constant dollars, the cost of extraction of uranium in constant dollars throughout the world, you can plot that, and I'm referring to the literature and look at the curves.

It has not gone up, it in fact fluctuates due to short-term market conditions, but over the long-term the constant dollar cost of uranium extraction has stayed fairly level, and, in fact, gone down slightly. That mimics the cost of extraction of all minerals, virtually all major minerals in the world over the last hundred years. Those data are available also, you can look at how the cost of mineral extraction has behaved over these long periods of time, including oil, and it reflects the fact that the efficiency in the extraction outpaces the depletion of the resource and also the ability to dig for deeper ore bodies.

Contrary to the early thinking, uranium prices have not been going up, and in fact you, as a Commission, to the extent that this influences your economic thinking, in my view, you should just include the cost of uranium out for the next 50 to 100 years, it's going to be about the same as it is today. Now, the capital cost of reactors on the other hand in constant dollars in the United States by about a factor of seven or more, and so contrary to getting on a learning curve, because reactors ran into these safety issues and licensing issues - - -

MR JACOBI: Sorry, just so we're clear, Dr Cochran, can I just interrupt there. You talked about the capital cost of reactors going up. Are you talking about fast reactors or are you talking about all reactors, including light water reactors?

DR COCHRAN: All reactors. I'm talking about light water reactors. They have gone up in constant dollars. The capital cost difference between a light water reactor and a sodium cooled fast reactor have gone up as well, so now when you look at the economics of fast reactors, particularly sodium cooled fast reactors because those are the dominant ones under development, there is absolutely no chance, in my view, that they will ever be economically competitive in the foreseeable future because you will never get to the point where the cost of uranium will increase so much that the fuel cost of light water reactors will go up and offset the very high cost difference between a fast reactor and a thermal reactor, a light water reactor.

MR JACOBI: Can I just pick up on something you said then. You talk about the gap in the capital costs between light water reactors and fast reactors, that the gap has increased.

DR COCHRAN: Yes.

MR JACOBI: I'm just interested to understand what you think is the best data source in order to make that comparison between the growth in capital costs or to what projects should the Commission pay attention in order to understand that.

DR COCHRAN: You ought to look at the French program and probably the Russian program. The Russian program is a little difficult because they don't tell you much, and the French program is a little old, but the French Superfenix, which was the commercial sized version of their fast reactor, and, mind you, everybody holds out the French, or at least they used to until they started building their latest reactors, held them out as the premier nuclear construction company because they were able to more or less standardise their designs and build a fleet of reactors and run them efficiently.

Their Superfenix costs more than 20 per cent more than a light water reactor, and I think the Russians, you can find it in the literature, I think you can find it in that report, I draw your attention to fast feeder reactor program history and status, that I co-authored one of the sections. There's some Russian data in there, but basically the cost of sodium cooled fast reactors is a good bit more than light water reactors, and you can see why. In a sodium cooled fast reactor, you have to isolate the sodium from air and water, and you eventually have got to heat the water to create the steam to run the generators and so forth.

You have a lot more equipment you've got to build, or details in the construction, to make that operation work, and it simply costs more than a light water reactor. Now, on top of this let's just compare the fuel cycle cost of the two reactors. In a light water reactor, we know what the fuel cycle costs are, with the exception of final disposal. In my view, final disposal is not going to be significantly different between the closed cycle, the fast reactor cycle and the open cycle. I don't think you're going to save much in the fast reactor cycle, it's not going to save much in the final disposal area, but reprocessing, if you go back to the AEC numbers in their cost benefit analysis in the late 60s, early 70s, they thought they were going to be able to reprocess spent fuel for about $35 to $80 a kilogram, depending on whether it's a thermal reactors or fast reactors, and that cost has gone up by more than a factor of 10.

It costs now, even if you paid for your reprocessing plant, it would cost you $1000 a kilogram in today's dollars. If you have got to build a plant, and you look at Japanese, and there's probably better examples, but as a $20 billion plant, it would cost you. The cost of reprocessing has gone up by more than a factor of 10. Enrichment cost, which are dominant, you know, for the light water reactor, the once through fuel cycle, the two dominant components are enrichment and the uranium ore costs.

Enrichment costs had not gone up in constant dollars, and there's a lot of room still for improvements in efficiency in enrichment technology, so light water reactor fuel costs have not gone up over the decades, but the cost of fuel if you're recycling has gone up by a tremendous amount not only at the reprocessing plant but at the (indistinct) so what you find is all of these nuclear facilities where there are significant safety and national security and proliferation issues, safeguard issues, the costs have gone up.

Other areas like mining uranium, the costs have not gone up, so the early nuclear pioneers back in the 40s and early 50s just got it wrong. They thought they were going to need to go to a closed fuel cycle and now, in my opinion, you would never on the basis of economics go to a closed fuel cycle and you will still find nuclear engineers who are enamoured with the idea of getting the most energy out of a gram of uranium, but that’s not the metric. The metric is to get the least cost electricity, not the – when you mine uranium in Australia there’s lots of minerals in that ore that you don’t recover. You don’t try to get the most minerals out of the ore and to be most efficient in recovery of minerals you try to do things economically and so you should dismiss these claims or these arguments that we need to close the fuel cycle in order to use the uranium more efficiently. If you do that you will buy electricity at a higher price.

MR JACOBI: Dr Cochran, I actually want to come back to that in just a moment, but there was one thing I wanted to ask you before we got there and that was the Commission has been urged to think about this particular class of reactors and I'm just interested to understand your views with respect to the risks associated with their development, that is bearing in mind what the track record has been with respect to success and failure of their construction and operation.

DR COCHRAN: We didn't cover all the fast reactor programs in this report I cited earlier, but we've covered most of them and I've, at least historically, had some familiarity with the others. Over this period from 44 to today around the world we've built something in the order of mid-30s, 35 or so fast reactors and you can study that history and read that report carefully, but I will just kind of summarise my take on it. About half of those fast reactors worked and about half of them didn't. Because of the sodium issue it's not a reliable technology and go back and read what (indistinct) has said when he jerked the sodium cooled fast reactor out of the Seawolf – actually he said this before the Seawolf went on sea trials he said, "We're going to take that reactor out and we're going to put a pressurised water reactor in the submarine", which he did because he said, and I'm paraphrasing, but the words are in the report, this technology it's expensive to build, it's difficult to operate, you have problems that are expensive to repair et cetera and that has basically characterised the history of this technology and you can look – this technology, again in the US, was the highest priority energy program in the United States and it failed. There's essentially no fast (indistinct) technology today in the US. There's some discussion of building a fast reactor as a test reactor because fast neutrons are very good for testing materials, radiating materials. Most of the damage in a reactor is from the fast reactors, not the thermal reactors, so it has some utility as a test reactor, but the program failed in the US, it failed in France, it failed in Germany and it never got off the ground in Italy. It is still the program that is most successful is in Russia. I wouldn't call it a success, but there's an entrenched bureaucracy of believers and they're pushing ahead with the (indistinct) series, BN600 and the 800 and they may go to 1200. The Chinese are getting in, the Indians have been in for ages, it's really tied to their weapons program and that program has not been successful and I would say to you you pick a country and name me a successful reactor like Rapsodie in France and I'll name you a failure like the Superphenix. The Superphenix, which was the flag ship, had a lifetime capacity factor of less than seven per cent. The Monde; you know, you can find the earlier reactor in Japan the most successful, the Monde was a failure. It has a lifetime capacity factor, it's still on the books, of less than one per cent. The US had failures and successes. The EBR-II was a good operating reactor. EBR-I was not, some of the earlier ones were not. The proponents for the technology will argue that if I can identify a successfully develop this technology, you can accept that argument. I would make a different argument. I would look at the whole array of reactors and tell you from a statistical stand point that you've got about a fifty-fifty chance that this thing's going to work successfully irrespective of the economic issues.

MR JACOBI: Yes. Can I just pick up a concept and that is is that the Commission has heard of the concept that fast reactors would be desirable because they can be used essentially to use the waste, and that is, to pick up your idea about a closed fuel cycle. I'm interested in where the origin of that concept came from because the origins that you've described from the 40s don't appear to be talking about it in those terms.

DR COCHRAN: No, I could be corrected, but I believe that that concept originated here in the United States because we've had so much difficulty in developing a geologic repository and the fast reactor community has had a habit over my 40 year career of "you give us a problem, we'll tell you how the fast reactors can fix it" and it was first, as we discussed, going to solve the energy problems and so forth, but they said, "Look, if we reprocess the fuel from the light water reactors, pull out the transuranic elements as well as the plutonium, long-lived transuranic isotopes, put them back in the fast reactor you can burn them as you do or (indistinct) them as you do the plutonium or change the neutron absorption or whatever and eliminate the very long-lived transuranic elements," so that idea caught on with the Department of Energy which was (indistinct) kind of research and under the Bush administration, Bush II, George Bush administration, they developed a program called GMAP which was based on – it was an R&D program to develop this concept. What was discovered after people started doing their homework was really to get rid of essentially all the transuranics let's just talk about an equilibrium just for the reactors that you operated. To eliminate the transuranics, a third of your fleet, roughly, has to be fast reactors. Two-thirds light water reactors, one-third fast reactors to burn the transuranics you're producing in bulk. Well, that's never going to happen because of the economics, for reasons I've discussed earlier.

Secondly, you would have to run this cycle for hundreds of years to eliminate the transuranics. That's never going to happen. You would have to have, you know, a planned economy like the Chinese or the Russians or something similar so that you could dictate how many reactors of each type you're going to build and so forth. Finally, even if you did it I would say the following. If you look at analysis of geologic disposal facilities like Yucca Mountain or the Swedish program, the Finnish program, the transuranics don't migrate very far.

They are not going to control the risk to future generations. They do control the risk way out into the hundreds of thousands of years, but that's not the main risk. What you are setting up, if you did this process, is a recycling over and over and over, and every time you recycled you're going to spew out at the reprocessing plant, and less so at the MOX plant, radioactive materials into the environment. The health effects from the recycle will be far greater, in my judgement. I don't have any numbers to refer you to, but my sense is that the health effects from the multiple recycles will overwhelm the health effects you would expect from the releases of transuranic elements from the repository than if you did it on a once through fuel cycle.

I don't think it makes sense economically, I don't think it makes sense environmentally, and recycling, in any case, carries all of this additional non-proliferation risk. At least it increases the non-proliferation risk certainly in the short-term over the once through fuel cycle. I would just point out that in the R&D program that DOE conducted for looking at various processes for recovering the transuranics with the plutonium, they did this work experimentally in a hot cell in Oakridge. One hot cell.

You could use that same single hot cell if you had an R&D program to recover enough plutonium for a weapon, so if you want to go down this route you're basically telling the rest of the world you want to get engaged in this wonderful methodology for lowering the risks, the long-term risks, at a repository, but if I were Iran or some other country I would jump at this. You would create a cadre of experts in plutonium, metallurgy (indistinct) chemistry, you would have hot cells to do the research, and you could do this research and you would reduce the breakup time for obtaining a bomb's worth of plutonium to zero, essentially to zero. A few days, a few weeks.

MR JACOBI: We've got two other topics we happy to deal with this morning. The next topic is to deal with the single pass fuel cycle, which I think we've already picked up, which is the single pass MOX reprocessing, and I think you've already touched on the economics associated with MOX fuel and also the development of reprocessing facilities more generally. I just wanted to pick up your views about whether you think that there are advantages or not with respect to that technology with respect to wastes.

DR COCHRAN: I don't think environmentally it makes sense to close the nuclear fuel cycle. I think you can compare an open cycle with direct disposal with, say, the Swedish program with the French program, from just a straight environmental standpoint you're going to get more releases from the reprocessing portion of the program than you will get from the repository, and you will set up an additional non-proliferation risk if you replicate that in a sensitive non-weapon state, plus your fuel costs are going to triple, or something on that order. It's going to be several times higher, so just done build it.

MR JACOBI: The Commission has heard, in the course of thinking about the nature of this activity, some suggestions that single pass fuel recycling reduces waste volumes. Do you have a view with respect to that?

DR COCHRAN: I think that's an argument you hear often from AREVA with respect to (indistinct) and they will tell you that they can reduce the volume of the waste. Okay, they can reduce the volume of the canister compared to the volume of the spent fuel in the dry cast store, but the volume of the repository, the geologic repository, and this is going to depend on what media you're in, it's not dependent on the size of the waste canister, it depends on the heat loading. If you stick to one recycle, you don't reduce the heat loading at the repository, so you haven't changed your repository requirements, all you have done is changed the volume of the waste canister, at great expense, mind you.

You have multiplied the cost of your fuel in order to reduce the volume of the waste. If I went into business, I would be trying to make money by reducing the cost of my fuel and not the volume of the fuel. If I make more money increasing the volume of the fuel, I would increase the volume of the fuel. It's not going to change the repository requirement.

MR JACOBI: Putting to one side the volume of that particular waste form, has there been any analysis done that's picked up the additional waste streams that would likely arise from reprocessing in terms of decommissioning wastes and other some such?

DR COCHRAN: I don't recall any. I certainly haven't read any myself or studied any. I wouldn't put that in. That's not a high priority, in my scheme of what's important here.

MR JACOBI: I wanted to come to the topic of non-proliferation, and we've read a paper that you've worked with Christopher Payne on international leasing of nuclear fuel cycle sites to provide assurance, and I just wanted to pick up your views, first of all, about the importance of multi-lateralism or internationalism associated with controlling proliferation risks.

DR COCHRAN: As a general matter, it's better to have international ownership of sensitive fuel cycle facilities such as an enrichment plant, because it would simply make it harder for the country to engage in weapon activities if they're a non-weapon state, but I must say there are ways that this is done that are less effective than others. You know, the IAEA has made a major effort to develop a stockpile of low-enriched uranium. It frankly didn't have any impact on Iran. The Russians have sold part of their enrichment complex to the Kazakhs so it's, in effect, an international enrichment. It hasn't had any non-proliferation impact.

So, you know, if I were looking at a - countries in the Middle East, you now have the UAE building reactors with the help of the Korean - I mean, the Korean reactors. You know, there was a US peaceful uses agreement with the UAE permitted them to go forward where the UAE says they won't engage in enrichment or reprocessing unless somebody else in the area does it. It would be certainly preferable if any country in the Middle East that was going to engage in enrichment did so - the safest alternative, if they wanted to get in the enrichment business, would be to have part ownership in an enrichment plant in a weapon state, for example, in the United States or in France, or wherever.

Not as safe, but better would be if their own enrichment plant were multinational and if it were sited in their country. The proposal that Chris Paine and I made was to say it sort of followed the - there was a program in the US following the Three Mile Island accident where the utilities outside of the Nuclear Regulatory Commission created an entity to sort of trade information on safety issues. So what Chris Paine and I tried to do is argue for the principal owners in the uranium business and in the reprocessing business to set up a program outside of the IAEA. You won't take away any of the functions of the IAEA, but put another layer together that would provide more international non-proliferation security than is currently provided by the IAEA.

If you look at the uranium case, you would argue that the IAEA safeguards, by themselves, are not capable of providing a timely warning at a large enrichment plant in Iran, but what we proposed was we'll create what we called nuclear hours. The country would turn over the footprint to the plant site to this international consortium and they would add a layer on top of what the IAEA does, a security system, and the country or the operator of the plant would comply with their requirements in addition to the state requirements and IAEA requirements, and those requirements could be pretty tough.

And so that's sort of what we were trying to propose, and we said if countries like Australia, Canada, Kazakhstan, the big uranium producers, together with countries that are now big in the enrichment business, like The Netherlands, France, Germany, they have to put this together and then go out to the world and say, "You're either in the club or you're out of the club. If you're in the club, you've got to comply with the club rules, which has all of this additional security apparatus. If you're out of the club, we're not going to do with business with you." So that's the general framework. It tries to do something that the IAEA is incapable of doing, but do it outside of the IAEA framework but, you know, working with the IAEA, but it takes some leadership of a country like Australia.

MR JACOBI: I just want to pick up on this distinction between why you consider that it would be necessary to develop a different concept as opposed to build on the existing safeguards arrangements.

DR COCHRAN: Because if you just look at the way the IAEA works and behaves and addresses problems, you see that the current system is incapable of providing a timely warning at bulk handling, sensitive facilities, and by that I mean uranium enrichment plants, large reprocessing plants, and (indistinct) each of those plants, the uncertainty in the inventory difference during the inventory period, the two stated deviations in sort of - if you plotted inventory differences over a long period of time and you made a distribution, and asked, "What is the width of that distribution?" the uncertainty is larger than a weapon's worth of plutonium. So even if the inventory difference were zero or negative, you still don't have any evidence that the physical security system is working.

So the IAEA cannot handle that function. The political problems, and getting into a facility, shutting it down, and so forth, are rather large. So if you put together a coalition of industrial partners that, for their own benefit and for the benefit of the world, created an additional layer of security, and penalties if you didn't comply, then it would enhance the current system. So I'm not advocating doing away with the IAEA. We were trying to build something to supplement it that would give us more security.

MR JACOBI: Do you see there being any particular challenges in industrial organisations joining together across each stage in the cycle in order to develop such an arrangement?

DR COCHRAN: Well, I would recommend starting in the enrichment business, not try to do enrichment and reprocessing at the same time. Get it up and working, just focusing on enrichment, and then further down the line, you can move to the other areas of fuel cycling. My preference would be to shut down the other areas of the fuel cycle, because I think the reprocessing doesn't have any merit from an economic, environmental or non-proliferation risk stand.

COMMISSIONER: Dr Cochran, I think that answers our questions. I thank you very much for your forthright evidence. It's been very useful for us to think through the various issues that are on the table.

DR COCHRAN: Well, thank you for having me. It's been a pleasure, and I must say, the reception now is much better than when we started.

COMMISSIONER: Thanks, Dr Cochran. We'll adjourn until 15.30.

DR COCHRAN: And I told your colleagues that my wife and I had a vacation in Australia and it was lovely.

COMMISSIONER: Good.

MR JACOBI: Thank you.

DR COCHRAN: It's a great country.

COMMISSIONER: Please come back. It's cheaper now.

DR COCHRAN: Yes, all right. We will. Thank you.

COMMISSIONER: Cheers.

DR COCHRAN: Goodnight, or good day.

ADJOURNED **[9.52 am]**