NUCLEAR FUEL CYCLE ROYAL COMMISSION

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SPEAKERS:

PROFESSOR FRANK von HIPPEL, Princeton University
MR JAMES VOSS, University College London
DR MICHAEL GOLDSWORTHY, SILEX Systems Ltd
DR PATRICK UPSON, formerly of URENCO Group

TRANSCRIPT OF PROCEEDINGS

ADELAIDE

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COMMISSIONER: Good morning. Welcome back to topic 8, Adding Value to South Australian Radioactive Minerals. This morning we'll hear from Professor Von Hippel from Princeton University, Mr James Voss from the University of London and Dr Michael Goldsworthy from Silex, and this afternoon Dr Patrick Upson from Urenco.

MR HANDSHIN: Today's public session is concerned with gaining an understanding of the feasibility of expanding South Australia's role into the so-called front end of the nuclear fuel cycle beyond the mining of uranium and, in particular, into the enrichment of that uranium so as to add value prior to its export. This requires the Commission to understand the nature and extent of current enrichment operations and their by-products and the development of new technology in uranium enrichment with a view to ascertaining whether it would be realistic and potentially beneficial for South Australia to become a participant in these activities.

The Commission will also seek to explore the risks attributed to enrichment activities, including the potential for any new enrichment facilities to contribute to the proliferation of nuclear weapons and the regulatory safeguards which are required to ensure against nuclear proliferation. This will be an introduction to a later public session dealing in detail with the topic of safeguards and nonproliferation.

The commercial enrichment of uranium which involves increasing the concentration of the main fissile isotope of uranium, U235, using centrifugal processes is currently undertaken by a handful of large and experienced organisations. These organisations currently meet most of the global demand for enrichment services which is presently exceeded by global supply. However, given the likely lead times to establish new enrichment facilities, the Commission needs to understand the potential commercial viability of additional enrichment services in the medium term. Given this future focus, the Commission intends to investigate not only current commercial enrichment technologies but also those in the later stages of development. Third generation laser enrichment technology invented by an Australian company, Silex Systems Ltd, has been under development for some time now and is argued by its proponents to be a potentially disruptive technology for the global enrichment services market.

Beyond enrichment, some written submissions to the Commission have urged its consideration of fuel leasing as a mechanism by which significant value might be added to South Australian uranium. Fuel leasing refers broadly to an arrangement whereby uranium is leased to a nuclear power facility or utility for use as nuclear fuel and then returned to the lessor as spent fuel for its storage and disposal. While the potential risks and opportunities presented by spent nuclear fuel storage will be examined in detail in later public sessions, the

Commission will today consider the topic of nuclear fuel leasing in the context of considering potential opportunities to add value to South Australian uranium.

The Commission's first witness this morning will be Professor Frank Von Hippel of Princeton University. Professor Frank Von Hippel is a theoretical physicist and Emeritus Professor of Public and International Affairs at Princeton University. He has worked on nuclear policy issues for over 40 years. From 1993 to 1994 he was the assistant director for National Security in the Whitehouse Office of Science and Technology Policy. He holds a DPhil in theoretical physics from Oxford 1962 and a BS from MIT in 1959. He was a founding co-chair of the International Panel on Fissile Materials and has written extensively on the technical basis for nuclear nonproliferation and disarmament initiatives and the future of nuclear energy.

COMMISSIONER: Professor, thank you very much for joining us this morning, this afternoon for you. Can I start with the broader question of your view of the nuclear industry at the moment?

PROFESSOR VON HIPPEL: At the moment – before I get into the substance, you're breaking up a little bit. So at some point it might help if we go off camera just for the audio. Let's see how it works, where we have it, but we may have some problems. I may ask you to repeat yourself or you may ask me to repeat myself. I think at the moment the future of nuclear power is very uncertain. It has been on a plateau, really, since Chernobyl. There was an anticipation in the middle of the 2000 to 2010 period of a nuclear renaissance but there was not that much of one and then Fukushima came.

So at the moment this plateau of global nuclear capacity appears to be continuing and it's possible that it even could decline in the future if the retirements outpace the construction of new capacity. In Europe and the US and Japan, the leading nuclear countries historically, the fleet of reactors is aging and there's a question of whether they'll be relicensed. In the US they have been largely relicensed to go 60 years and there's even some talk of relicensing them again to 80 years but that's very uncertain. So I think the one bright spot is really in China where about half of the nuclear power plants that are under construction are located but it's still a very small fraction of the global capacity that China is building. The IEA's expectation ranges from a plateau to maybe a doubling in global capacity by 2050 but because the rest of the non-nuclear capacity will be growing, at most maintaining the percentage of global electricity production which is about 11 per cent now.

COMMISSIONER: Professor, it might be a good time – in some of the submissions the Commission has received it has been put to us that the need to reduce greenhouse gas emissions from power generation might be a reason for a renaissance again for the nuclear industry. Do you have a particular view on that?

PROFESSOR VON HIPPEL: I think that's true but in the US and Europe it appears that wind and renewables are outcompeting nuclear. Nuclear has become so expensive. Japan, it's in an earlier stage, I think. I personally don't think we should turn our back on any non-greenhouse emitted energy technology but so far, of course, the global climate change policies is at an early stage and it might be that if it strengthens then it will lift all boats, including nuclear.

COMMISSIONER: Thank you. If we can now move on to the specific area that we're focusing on today, which is enrichment, conversion, fuel fabrication. Can you give us a sense of your view of each of those particular areas and where you see demand and supply at the moment?

PROFESSOR VON HIPPEL: This is more in the area of expertise of some of your later witnesses from Silex and Pat Upson. It really does again depend on global nuclear capacity growth. At the moment my simple way to orient myself is to look at the price of uranium and the price of enrichment work. They both plunged in the last few years, in the case of enrichment work by more than half, and so that suggests that there's an overcapacity at the moment, and I think the fact that GE Hitachi, which is going to build a laser enrichment plant (indistinct) laser enrichment plant in the US, that they postponed their plans similar to (indistinct) which is going to build an enrichment plant in United States, a centrifuge enrichment plant has postponed this, it was on the (indistinct) because that at the moment - you know, and I don't know how long this will last, you know, the conditions aren't good for a new entrance. We've come to fabrication. I don't know. That's a smaller part of the fuel circuit.

MR HANDSHIN: Professor, could I just pick up on one matter that you raised in your opening remarks, and in particular your reference to China. Is there any indication of whether China is predisposed to vertical integration of its nuclear industry?

PROFESSOR VON HIPPEL: Yes. China is building a lot of immersion capacity and it looks like it wants to be self-sufficient in that area. They are expanding their uranium mining, but I think quite aggressively taking positions outside China and trying to acquire long-term contracts, I think, including Australia, probably South Australia. So would the country be processing? I don't know whether that's on our agenda today or not. You know, I think there's a debate in China about whether to reprocess, but if they do, then I think they will - they won't ship their fuel elsewhere. They would build it domestically.

MR HANDSHIN: What kind of enrichment capacity does China currently have?

PROFESSOR VON HIPPEL: That's a mystery, because, you know, I have a colleague who's been trying to pull that together, a Chinese colleague, and he has found many more enrichments plants then we were in China. So I guess I could try to pull something together and send it to you by email, but I don't have (indistinct) you know, it's been around two main sorts. It may be double that at this point.

MR HANDSHIN: Does China currently provide enrichment services outside of their own domestic market?

PROFESSOR VON HIPPEL: They don't, but I think they're in a renaissance stage. I think the Chinese are looking to become an exporter of nuclear reactors, at least, and if they model themselves on the Russians in that regard, I mean, they'll try to provide all the services for those reactors that they export, but, you know, they're not as well positioned as the Russians are. It's only in the enrichment area the Russians have about half the global enrichment capacity.

MR HANDSHIN: Do you see any potential issues with respect to the degree to which Russia is involved in the enrichment market and how that might be affected by geopolitical issues?

PROFESSOR VON HIPPEL: Well, I think the Russians - you know, trying to explain the huge amount of enrichment capacity that they built, partly it was initially for weapons, as it was in the US. The US built actually, and has retired, a lot of enrichment capacity, maybe comparable to what Russia is. We kept going with gaseous diffusion which became less and less economic in competition with centrifuge enrichment. That's why our system capacity has been retired. Russia doesn't have that many exports and so I think nuclear - exporting nuclear reactors and services is one of the few areas where they are competitive, besides oil and gas, and so, yes, I suspect that they're happy and they might even, if they could, increase their share.

MR HANDSHIN: If there were an unavailability of access to Russia's enrichment services would that create a gap in the enrichment market?

PROFESSOR VON HIPPEL: I think it would, yes. I mean, certain countries of course are trying to do as little business with Russia as they can right now and that's a good point, and if there were really long-term sanctions on Russia, by their nature, you know, by Europe, by the US, in that area - you know, I actually don't know what it is. I mean, we know we have some sanctions. I don't know whether there are some in the nuclear area as well. You know, that would certainly have a major impact.

MR HANDSHIN: You referred a moment ago, professor, to a SWU, a separative work - - -

PROFESSOR VON HIPPEL: (indistinct)

MR HANDSHIN: Could you give us an idea of where that concept sits in the context of enrichment and what it measures?

PROFESSOR VON HIPPEL: Yes. It is what the - a separative work unit, a SWU, and it is the - what the enrichment services providers sell, and for non-enriched uranium the - roughly speaking, to produce the four to 5% enriched uranium that one or two reactors use, it takes approximately 1 SWU per kilogram of uranium, 1 kilogram SWU. Sometimes people talk about tonne SWUs, but I think it's almost always kilogram SWUs in common usage.

And so to give you an idea, to translate that into centrifuge units, your really primitive centrifuges that Iran has built produce about 1 SWU per year, whereas Urenco enrichment - well, Russia's centrifuge produce around 10 SWUs a year and the Urenco, the most recent generation, around 100 SWUs per year. The Russians have a different philosophy where they stack up actually vertically. They stack up these relatively small centrifuges and it's different from Urenco which has gone to larger and larger centrifuges.

MR HANDSHIN: So is that SWU measurement that you gave us in relation to Russia and Urenco a measurement that relates to each individual centrifuge?

PROFESSOR VON HIPPEL: Yes.

MR HANDSHIN: Right. So then you add of those - - -

PROFESSOR VON HIPPEL: Yes, per centrifuge.

MR HANDSHIN: Yes.

PROFESSOR VON HIPPEL: So one for the Iranians, 10 for the Russians and 100 for Urenco. These are ballpark numbers.

MR HANDSHIN: Yes, sure. And in order to determine the overall capacity of an enrichment facility, do you add together, effectively, the capacity produced by each individual centrifuge?

PROFESSOR VON HIPPEL: Yes, to a (indistinct) approximation. You may lose some enrichment capacity if the - cascade, they're called. They're arranged in cascades where one centrifuge feeds into another centrifuge which enriches a little bit further. If there is no optimal design, you can lose some of the output in that way, reduce the overall output from what you could get by simple addition.

MR HANDSHIN: Perhaps given that we got into the topic of the enrichment process, could you provide us with a little more detail on how it works and the process of centrifuge?

PROFESSOR VON HIPPEL: Yes. The way that centrifusion works is you convert uranium oxide which is the form that you mine in Australia in to uranium hexafluoride, uranium with six fluorine atoms which is a gas. And so then you feed in to these cylinders which are spinning very rapidly, I like the analogy to cream separator, centrifugal cream separator and the gases is pressed against the outer – outside of the cylinder and the – we have two isotopes in uranium, u-235 and u-238. U-238 is about one per cent more heavier than u-235 and therefore pressed a little bit harder against the wall and as with cream, you get a slightly enriched of the layer toward the centre is slightly enriched in u-235. And so maybe if you put it in at seven tenths of – for a uranium centrifuge, if you put it in in seven tenths of a per cent, that’s natural uranium has seven tenths of a per cent u-235. Maybe comes down to .8 per cent. And then you feed it in to the next layer of the cascade.

COMMISSIONER: Okay. Could I perhaps move on to the topic that I know you’re interested in, reprocessing and to have - - -

PROFESSOR VON HIPPEL: Yes.

COMMISSIONER: - - - your views? Perhaps start with just a brief explanation professor on what reprocessing is and then perhaps tease out the issues that I know you are particularly concerned with?

PROFESSOR VON HIPPEL: Yes, thank you. Well, when you put nuclear fuel in to a reactor it contains maybe about four to five per cent u-235. When you take it out, so it’s – at that point it’s called spent fuel, it – most of that u-235 is inefficient and about one per cent of the uranium-238 that is the other 95, 96 per cent of the uranium you put in, about one per cent of that is converted to plutonium. And the other per cent actually has been converted to plutonium but efficient fuel was in the reactor. The plutonium, is like u-235 chain reactive and originally the rationale for reprocessing was to separate the plutonium out to start a new type of reactor which could actually be fuelled by u-238. It would be fuelled by – immediately by plutonium but it then would convert more u-238 in to plutonium with the extra neutrons it produced, than it used. And so these were called plutonium breeder reactors and the idea was that you would be able to get a 100 times – roughly a 100 times as much energy out of a kilogram of uranium. Now the type of breeder reactor that was developed was cooled not by water but by liquid sodium and that turned out to be trouble, sodium if it comes in contact with other air or water burns. And so most of the cost of nuclear power is the cost – the capital cost of the power plants and these liquid sodium cooled power plants turned out to be much more expensive than water cooling and so despite about 100 billion dollars of effort and 50 years, these – and even those – two countries, in particular Russia and India are still trying to commercialise these reactors. They haven't been commercialised.

So then the question – but in the meantime, in a few countries, notably France and the UK, those are countries which built new processing industries were built to separate out that one per cent plutonium and spent fuel, for start up fuel for the breeder reactors that didn't come. So then the question was what to do with that plutonium. France has pioneered in the idea of recycled – using that plutonium in – to fuel the water-cooled reactors, to recycle and to fuel their water-cooled reactors. That promotes (indistinct) That can has reduced France's uranium consumption by about 12 per cent, not very much. Much less dramatic than the effect that breeders would have had. And it's been very costly. Reprocessing, the cost of reprocessing were grossly underestimated originally. They increased about tenfold and France has found, and Japan which has been less successful than France, they found that the cost of the so-called mix outside fuel which is a mixture of a few per cent plutonium with depleted uranium. This fuel has been used to recycle the plutonium. It costs about ten times as much as the (indistinct) uranium that it displaces.

In France and Japan, it has been found to be very difficult to change (indistinct) and the utilities are being made to eat that extra cost by their governments. My concern, of course the reason I am interested in this is plutonium is a weapons material and separating it from - and (indistinct) makes it much more accessible. In fact, for a while the US forgot this in the sixties and was promoting reprocessing and breeder reactors as the energy technology of the future and then one of the countries we were promoting it to was India and India had - we were in fact (indistinct) for peace programmes supporting India's development of reprocessing and breeder reactors and then India used the first plutonium that it separated in 1974 for a nuclear explosion and that caused the United States a very dramatic rethinking. You know I became involved at that point. I was much younger and the – I was part of the Carter administration's review and the question was do we need to do this? And we concluded that what in fact just turned out to be the case, that breeder reactors would not be economic. Reprocessing would not be economic and US abandoned its efforts in those areas and tried to persuade other countries to do so too.

Countries that were pretty far down the road, namely France, Britain, Japan, Russia were not willing to be persuaded to stop. But the effort has been successful in preventing new countries from getting in to this business. Basically we have taken the position that we don’t do it, you don’t need to do it either.

MR HANDSHIN: Professor what level of global demand is there at the moment for reprocessing?

PROFESSOR VON HIPPEL: Well, at the moment the countries which have been reprocessing for other countries are France, UK and Russia. And in the case of – in all of those cases, the demand has essentially evaporated. In the case of the UK, because of the economics and because the exporting your fuel to France or the UK was not a solution to your radioactive waste problems because part of the contract was that they were going to ship the high-level waste from reprocessing back to you, and it turned out to be that it's politically no easier to deal with, that high-level waste, than the original spent fuel. But in the case of the UK even its own utility which, interestingly enough, is Électricité de France – Électricité de France did buy all the UK nuclear power plants – has refused to renew their contracts. So the UK's plan is to finish up the current contracts and, if the plant works reasonably well, it expects to be done by 2018.

In the case of France one country did renew its contract, the Netherlands. The Netherlands only has one very old nuclear power reactor. So that more than 99 per cent of the reprocessing in France is of its domestic Électricité de France's fuel because of the insistence of the government which – I think their reprocessing plant employs thousands of people in a rural area and I think that's sort of an industrial policy to keep them going.

Also, France has been trying to sell reprocessing plants. It's not clear whether it's succeeding with China. The price that was being cited for China was 20 billion Euros. So that's quite a bit of money for French exports and I think that might be another reason in addition to the employment for France to keep its own reprocessing business going, because even if it can't sell the services, maybe it can sell plants. It also has been lobbying very hard in the US to sell the US reprocessing plant. The Bush administration almost bought it. The Obama administration hasn't been interested.

So we come to Russia. It's a little more confusing. It may be that Hungary is renewed. It may be that Armenia – it's not clear what the situation is for those countries. Otherwise, though, there have not been renewals. The Eastern European countries which joined the EU have not renewed.

MR HANDSHIN: Professor, you mentioned a moment ago a number of the disadvantages, in your view, with reprocessing facilities and I think you mentioned proliferation risks and the costs involved in the operation of these facilities. Do you see any other downsides to them, perhaps environmental, radiation-related issues?

PROFESSOR VON HIPPEL: Well, I think in my own view the environmental issues of deep burial of spent fuel are not very large. One of the arguments used to promote reprocessing has been that you would then not bury plutonium and that plutonium is very long-lifed and who knows what kind of leakage on that time scale might have. That argument is stronger if you have bigger reactors where you really do fission all the plutonium or almost all of the plutonium eventually. In the case of light-water reactors the current plan is only to send the plutonium around once and then that would only reduce the amount of plutonium by about half which doesn't change the situation qualitatively. At the same time, of course, you take one radioactive waste form, spent fuel, and turn it into multiple waste streams, including the plutonium-contaminated waste streams from MOX fuel fabrication.

So it's not clear if there's an environmental advantage. Certainly in the US in the 1990s that was one argument that was being made and the National Academy of Sciences was asked to review that and they concluded that there was a very moderate, if any, environmental benefit at a huge cost.

COMMISSIONER: Could I just pick up on one of your points, Professor, about sodium-cooled reactors and how far they are away from commercial development. Are there any other reactors that are capable of burning spent fuel that you think are closer to commercialisation?

PROFESSOR VON HIPPEL: In terms of multiple recycles, I guess, you're asking. I don't think so. There is one reactor type which has sort of been also at the threshold and never quite got across the threshold, which is called a high temperature gas-cooled reactor. Its proponents say that one of its advantages, even on a once-through basis, is that it can burn a larger fraction of the plutonium than the water-cooled reactors. It also has been attractive to some of us because of its safety advantages but it's a perennial – there has been interest in South Africa. Now currently the Chinese are interested at a prototype level. The US built a couple in the 70s. They didn't work very well but not for fundamental reasons. Somebody else might make them work better.

There are advocates, of course, for many different types of reactors. There's a group that's promoting a molten salt reactor where the fuel is more – but it's quite complicated in the sense that it's a reactor and a chemical plant combined. I'm pretty sceptical myself. The other boomlet in the United States has been with regard to smaller reactors, small modular reactors, which some people argue that if you could get them into mass production they could be less costly than the permitted capacity, than the large reactors that dominate the market today, but they wouldn’t be different as far – qualitatively different. They would be water cooled.

Recently I looked at the design of the shipping port reactor which was the first light-water cooled reactor. I think it came online in the United States – it was built by the navy, the navy reactor people. It came online back in 1960 and it's amazing how little change there has been in reactor technology since then. The industry doesn't seem to pursue novelty, new reactor types.

COMMISSIONER: Professor, I think you were leading into the potential for spent fuel repositories being a better means of managing waste. Can you just tell to us about where you see spent fuel repositories going, what you've seen in the world, what you think has worked and what you think might work in the future?

PROFESSOR VON HIPPEL: I'll explain my hierarchy of concerns about nuclear power. I put proliferation at the top, reactors accidents in the middle, and radioactive waste repositories at the bottom. The public hierarchy is reversed, I think, and so if there was a rational country out there, you know, which didn't have - well, let me just explain why the evidence - that in fact in - in some situations, you know, that perception is shared by others.

The repositories that are furthest down the track are in Sweden and Finland and the sites of those repositories are adjacent to nuclear power plants, and I think that those communities do understand that spent fuel above ground - spent fuel in reactors is the most hazardous. Storage spent fuel and dry casks (indistinct) maybe is the next. The least hazardous is the spent fuel 500 metres underground. I mean, it could be that in a community like that, maybe one which becomes more sophisticated about the risks because they do host a reactor, you know, could actually make a lot of money by saying, "We'll take other countries' spent fuel."

I think that a well-designed repository 500 metres underground, when people do calculations, simulations, of over thousands of years, tens of thousands of years, very little material gets to the surface even in worst case analogies, and the material that does get to the surface tends not to include plutonium because plutonium is not - in most groundwater, plutonium is not very soluble. Other elements are more soluble. You might get a more sophisticated (indistinct) in this area (indistinct) you might get a more sophisticated perspective by somebody who has really gotten into that more deeply. I could suggest a couple of names to you if you decide to pursue that.

MR HANDSHIN: Thank you. Have you heard of the concept of fuel leasing, professor?

PROFESSOR VON HIPPEL: Yes, and that's basically what Russia does, and basically - and that's one of the appeals to countries, you know, that Russia sells reactors to, that they included in the service that they will take the spent fuel back. Russia at one point was considering taking other countries' spent fuel back, spent fuel from reactor power plants that they had not sold, and that was just too much for the Russian public even, you know, with the control that the central government has, but they - they argue because they're still imagining that their future source of nuclear power be (indistinct) reactors that spent fuel is not a waste. It's a resource, and therefore, you know, they ultimately will need that plutonium to start up an expanding fleet of plutonium (indistinct) reactors.

I don't know of any other country which has done that, but I think it is interesting, you know, because my perspective on that actually - the public is not objective about the risks of spent fuel. I think, in fact, if a country wanted to make fresh fuel, sell it and take it back, put it into a repository, you know, that could be quite a profitable business.

MR HANDSHIN: And how would you see Australia's appeal as part of involvement in a fuel leasing arrangement?

PROFESSOR VON HIPPEL: Well, I mean, the appeal of Australia to be also as a potential host for an enrichment plant if the situation opens up again. Its non-proliferation credentials - you know, there just hasn't been any indication. I don't know. Maybe in the 60s there might have been some interest in nuclear weapons in Australia, as there were in many other countries, but certainly not in recent times, and so, you know, I would be much more comfortable with an enrichment plant in Australia than I would be in Japan or South Korea, you know, where there are security threats and want to preserve a nuclear weapons option.

With regard to spent fuel, you know, I also - I mean, in some countries we're not comfortable with spent accumulating. That's certainly been the case with Iran where part of the deal with Iran is that its spent fuel will be exported just because plutonium contains - which with time, becomes more accessible as sufficient (indistinct) decay, and I think in that case it's Russia that will be taking Iran's spent fuel. So I think there is some appeal from a non-proliferation ground. I wasn't being that encouraging in terms of the commercial prospects in the near term with regard to enrichment but from non-proliferation grounds, I'd be happy to have South Australia explore the opportunities in the long term for a fuel leasing arrangement.

COMMISSIONER: If I could just finish with that sort of question, professor. A multinational enrichment facility, do you think that would have greater appeal to the international community?

PROFESSOR VON HIPPEL: Well, thank you very much for bringing that up, because that was - I forgot to include that. Right now I'm on a campaign arguing that there should be no more national enrichment plants and that - you know, because with an enrichment plant does come breakout potential, as we've seen, you know, with this crisis over at Iran's enrichment plant. You know, normally that enrichment plant is designed to produce three and a half per cent enriched uranium for the Boucher nuclear power plant, but it could - the cascades could be fairly quickly reconnected to proceed weapons grade uranium.

That's been the concern, and the concern is if Iran goes down the road and succeeded and just by persistence, is willing to - willingness to absorb the huge costs that it's incurred and has a national enrichment plant, then other countries, you know, Saudi Arabia, Turkey, Egypt, in the region, may say, "Well" - you know, in fact a senior Saudi official has said, "Whatever Iran has, we'll have too." And so you get a proliferation of nuclear weapons threshold States. So, you know, what I'm promoting is say, "Let's just get out of the national enrichment business and all future, and hopefully some existing, enrichment plants should be multinationalised.

Now, the situation is with Urenco, it's going to be multinational. Germany, The Netherlands and the UK own it. It accounts for about a third of the global enrichment capacity. So as an existence (indistinct) I don't know, I think it's optimally designed with non-proliferation in mind in terms - but whether it is an existence (indistinct) that is economically viable, and similarly, you know, I've been thinking that, you know, a multinational arrangement starting with Australia, Japan and South Korea, for example, could keep the pressure off us from South Korea, at least, to have its own enrichment plant, and maybe persuade the Japanese to retire their enrichment plant which has not been economically competitive. So thank you for asking the question.

COMMISSIONER: Professor, I think we asked all the questions that we sought from you. I thank you very much for your time late at night, and I wish you the best for the future.

PROFESSOR VON HIPPEL: Thank you. I enjoyed it. Bye-bye.

COMMISSIONER: We'll reconvene at 1000 with Mr James Voss from the University of London.

ADJOURNED **[9.21 AM]**

RESUMED **[10.00 AM]**

COMMISSIONER: We will reconvene and welcome back. We are on topic eight, Adding Value to South Australian Radioactive Minerals and we welcome Dr Voss. Counsel.

MR HANDSHIN: James Voss holds qualifications in nuclear engineering from the University of Arizona. He has worked in a number of countries in areas including radioactive waste management, nuclear fuel storage, renewable energy and environmental sectors. Mr Voss lectures at multiple universities and has held leadership roles wit a number of organisations concerned with the management of nuclear material, including Golder Associates and Geo Resources Pty Ltd and a potential business that would be involved in fuel leasing called Resources Solutions Australia.

COMMISSIONER: Mr Voss, thank you very much for joining us. We are particularly interested in this section of our discussions in adding value and for you, with your background and experience; I would like to explore fuel leasing. So perhaps we could start with your notion of what fuel leasing is and why you think that adds particular value. And I know you have some knowledge about South Australia, so perhaps you could provide some context as you go through your explanation?

MR VOSS: Thank you. The notion of fuel leasing that we have is to own the – that is some entity would be formed that would own the Australian produced uranium. It would establish contracts with nuclear utilities. Those contracts would require that the uranium be made in to fuel for those companies. After the fuel was used and sufficiently pooled, it would be returned to Australia for management. That management would be, in my mind, long-term storage while a decision is made either to recycle the residual material, or to dispose of it. So that comprises the technical facets of it, the activity facets. There are some who believe that the added value is in what is referred to as the front end of the nuclear fuel cycle. That is converting the yellowcake in to UF6 then enriching it, then making it in to fuel. We look at the numbers – there are two reasons we don't think that this is a particularly attractive notion of adding value. The first is that it is a relatively minor part financially of the total beneficiation process involved with nuclear fuel, where the majority of it is actually on the back end.

The second reason is that there is an oversupply of all of those front-end functions in the world. Consequently, if Australia were to say – some entity were to say let's construct these facilities in Australia and do the beneficiation on the front end, what they would be facing is a global marketplace with an oversupply and pricing – downward pricing pressure. The ability to raise debt or equity to construct those facilities, the billion of dollars needed would be a significant challenge. Our view is that the scarce commodity right now, in the global marketplace, is the back end management of nuclear fuel. Our view is that there is sufficient demand amongst significant customers in the world for the services that the entire Australian uranium supply could be allocated within a leasing structure through a – and the fuel would be properly managed and it would be remunerative and beneficial to the Australian people.

COMMISSIONER: Can I interrupt there Mr Voss? Unpack a little of the worldwide supply of conversion enrichment fuel fabrication. Can we just walk through who the major players are and also where you see demand going in to the sort of medium term, the next 10 to 15 years?

MR VOSS: Right.

COMMISSIONER: Perhaps start with conversion?

MR VOSS: Look I am not going to hold out that I can quote each of the companies involved. In doing our research, what I have done is gone to the literature to find what the literature says on this matter and then gone to experts and asked them the same questions. Clearly, and everybody is repeating the same conclusion to me. And I mean clearly an organisation like Urenco is a dominant enricher in the world, the Russians offer various aspects of this, in each aspect of this. There are US suppliers, European suppliers. I am not going to attempt to defend who they are, or suggest who they are. The question of the nuclear demand in the next 10 to 15 years is actually pretty straightforward. Recognising that nuclear power plants take a decade or so to be built and come on line, the demand in the next 10 to 15 years, in my view, is going to come in from India, from China. There will be a – there may be a growth in the Middle East. We have heard lots of things from Saudi Arabia but haven't actually seen particular actions.

On the other hand, the Emirates are very active with their five-reactor programme and are considering more beyond that. There is the Eastern European block that is moving steadily in to new reactors. Now beyond that, the US is certainly not a growth sector, given the price of natural gas in this country. Canada, I can't comment on; currently Canada is not a particular marketplace for Australian uranium. The Koreans seem to be moving toward an expansion, although I think they have some internal struggles to get past. Japan is clearly not going to expand their nuclear power programme in the next little while and that brings us back to Western Europe. We know that England will move some steps to building, Germany will not. France has announced a higher push on renewables, non-nuclear renewables. So when I look at that total picture, where I see the market opportunities for Australian sourced material, in a bigger sense is the Emirates, possibly the Sauds, Korea, India. China is a possibility with some complexities. Beyond that, the Japanese, as they restart their programmes, I do not know what their long-term contract commitments are for their reactor fleet. Whether that is a marketplace or not, can’t comment.

COMMISSIONER: All right. If that's the market as you see it and a mixed view about the future of the industry in terms of its growth path, can you just take us through how you would establish the path towards a long-term storage site? What would you have in mind in terms of time frames and processes?

MR VOSS: Let me call it a two-pronged business discussion. The first prong is the contracts, the supply side. I would focus my attention right now in Korea, the Emirates and in India to establish long-term supply arrangements. In terms of the domestic programs, clearly there's a massive amount of contract work, treaty work, multilateral and bilateral treaty arrangements that have to be structured as well as contract work to get all of that front end established credibly. There would need to be a storage facility for spent fuel, a receiving and storage facility in Australia. There are many, many models of it around the world, in Germany, smaller versions in the United States. In our submission we've given you some pictures but these are very well established engineering facilities.

There would have to be a consent-based siting program that went on in Australia to come up with a site for this facility. Clearly, that site has to either be near a port or has to have very good transportation lines from a port. There is a massive industrial infrastructure that has to evolve also. The development of a shipping fleet is needed for this. We have submitted information on our view of what that fleet looks like but if we model it after the organisation in Britain known as PNTL, the model is a series of five to six thousand tonne vessels that have to be constructed, purpose built, for this application. There also needs to be an infrastructure for the construction of shipping casks or flasks, referred to interchangeably. These are massive steel products and they have to be – as has been discussed right now in the Australian discussion of submarines, there are people who have the designs and the rights to these products. We would want them, however, manufactured in Australia.

As this industrial infrastructure and nuclear infrastructure evolves, there also then has to be a long-term program undertaken to develop a disposal site for material. This is, in my opinion, a decades-long process. Too many programs have walked out and driven a stake in the ground and say, "This is the place and then we'll defend it." I don't think that's productive and it would be counterproductive. So that program has to go on at the same time. It's a complex undertaking with many, many failure paths but to undertake it could have some significant benefits to world securing of the nuclear material in the world. It could have massive complements to help having Australia reduce the carbon emissions in the world, far more so that it can domestically, far more so.

So it's simply an opportunity that, if there is consensus and support for that opportunity, we think the capital and the manpower and the staffing can be undertaken to get it right and make some massive contributions to the world but also to deliver some benefit to Australia.

MR HANDSHIN: Mr Voss, in the course of that answer you made reference to this being a complex undertaking. Amongst other things you said that there are many failure paths, some of which might be implicit in what you've just told us but I wonder if we might get you to illustrate what you contemplate as being some of the difficulties in getting a concept like this into an operational phase.

MR VOSS: The principal failure path is the perception that such a program would breach the social contract that exists within Australia and its citizens. If the Australians believe this breaches the social contract it will not get off the ground. For those who know the history of Pangea, for example, there is a case in point where the concept, albeit not proposed by the government but proposed by a private entity, was viewed by very many as a breach of the social contract. But not just in Australia. I've been doing some research on siting efforts in the last 40 years in democracies for these facilities. The landscape is littered with failures and the failures all are driven, with a couple of exceptions – they're almost entirely driven by breach of the social contract. If you don't have the political support, the public support, for one of these you're not moving forward.

Now, there are always technical things that have to be exactly right. Australia is blessed with the best geology on earth for managing nuclear materials. That doesn't mean that every site is qualified but what it means is that there are many, many options within the nation where this could be done. If you will, there are political failure modes, there are technical failure modes which we believe are manageable, and of course there are financial failure modes. Whether the business is a government public-private partnership, a corporate endeavour, whatever the structure, it still has to make fiscal sense. So there's that failure mode. I'm sure there are others but in the broad categorisation of things that's how I would put it.

MR HANDSHIN: What do you see as some of the options from a funding perspective?

MR VOSS: The front end is going to entirely be done with what I would call equity. There's an enormous risk of failure at the front end. I think it's just going to take corporate investors who are willing to put money in. Obviously they're going to want to see a path for remuneration with that investment. Once that investment has been made and the front end is successful, it's my view that, yes, maybe some additional equity is needed but the substantial part of this will be handled through advance payments from customers, possibly debt facilities to take advantage of the bankable nature of the contracts.

MR HANDSHIN: Can you just perhaps clarify for us so that we all know what the parameters of the discussion are what your understanding or what you're meaning to convey by "front end" in this context?

MR VOSS: The dominant success goal would be the ability to enter into contracts with utilities for leasing. In order to do that there are a number of things that have to be accomplished. There has to be the treaty infrastructure between nations. The analogy that I would use is the Basel Convention on the Safe Management of Hazardous Wastes. So this a framework under which the nations agree hazardous material can move between boundaries and can be managed. There are then protocols under it for implementation. So there is no such framework in the world right now for this activity. The Basel convention is a great model but it excludes explicitly nuclear wastes.

There clearly has to be a siting undertaking – siting of facility for storage. Within that, there has to be a broad set of agreements with the host – with South Australia, using that – within the context of these discussions. This might be an equivalency to the indenture agreement between Olympic Dam and the state. But this would have to be in place. Those pieces are what I refer to as the front-end. There are many other things that have to be done that are second tier in that but if you – when I am speaking of the front-end, what I'm thinking of is, I am now presenting a contract to a customer. For that customer to enter in to the contract, there has to be a broad set of things done before that customer can do so.

MR HANDSHIN: Can we just develop the idea of advance payments a little bit? You referred to that a moment ago. Can you tell us how you would see that working and how that fits in with the way that the nuclear fuel cycle currently operates?

MR VOSS: The nuclear fuel cycle – the nuclear economy is quite accustomed to paying in advance for long-term management of nuclear materials. In most situations the nuclear plants are required to – nuclear utilities are required to pay in advance for two items. One is waste management and the other is for decommissioning. So there is an entire infrastructure in place within the rate structuring, the tax structuring, financial management of nuclear power plants, for these payments to be made on the basis of electricity rates. The notion of then saying to a customer, okay we are going to lease you nuclear material and we are going to take it back for management, it would be perfectly reasonable for that customer to say, yes, I understand, I will start making progress payments, or advance payments along the way, much as they would for any of these opportunities.

COMMISSIONER: Can I perhaps change the direction of the discussion and understand the facility that you are proposing?

MR VOSS: Yes.

COMMISSIONER: You have talked about storage, as opposed to disposal?

MR VOSS: Initially, yes.

COMMISSIONER: So can you explain in a little more detail, how you envisage, should we decide that that is an economic and safe process - - -

MR VOSS: Yes.

COMMISSIONER: Talk about safety in a minute but just give us some idea of how you see that site evolving over time?

MR VOSS: Right. Let me start by saying that there are broadly two ways you store spent fuel. You store it in water, or you store it in dry. Without looking at what exactly these facilities would look like, I will lead you down the path, down both paths.

COMMISSIONER: Okay.

MR VOSS: Spent fuel would be transported in very large casks to a facility in Australia. At that facility, the casks would be opened and the nuclear material taken out. Now this is done in one of two ways. It is done in either a – what is referred to as a hot cell, a large concrete facility that is in – everything is contained within that facility. So you would open it up, take the nuclear material out and if you were doing that, you may put – you may go directly in to then a dry storage cask. This is one way to do it, or you might move it directly in to a dry storage vault. A centralised facility that would – in which you would store it, a warehouse. If you put it in to a storage cask, this cask might be a concrete steel composite and you would put that – you could either put it inside of a facility; a model of this is in Ahaus in central Germany, or you might put it out on to concrete pads outside of the facility, just open to the environment. These casks are extraordinarily robust, they are certified for every terrorist threat, every – certainly every natural disaster, crashing a plane in to them, these sorts of things. All of these facilities fall within that category.

On the other path, if you chose to do a wet storage, then you would have a very large pool in which the material is stored within the pool. There are – and so you would bring the cask in from the ship and actually put it under water and open it under water. So these are the two concepts. I couldn't – wouldn't want to speculate how it would be best to do it. My own view is I would rather store it dry but that is a narrow engineering perspective that may not be supported in the end. So this storage facility, if it was at a port, might – gosh, I would have to think about the size, hundred hectares would be sort of the maximum I could wrap my head around. But I wouldn't want to argue for that.

COMMISSIONER: Yes.

MR VOSS: But most of that is actually just buffer zone and security zones. The facilities themselves are not that large. The car parts on which you put these flasks for storage are not that large. Nor are the pools. So that is the front end, that is the storage aspect of this. After an appropriate period of time, there will be a decision made about whether to recycle the nuclear material that is inside – that is contained within the fuel, or to dispose of it. It is a monumental decision. My own view is that it probably would be – would not make economic sense for a very long period of time to recycle it. Hence I would personally be moving toward finding a disposal solution in the long term. But that is – that can go either way. But even if you opt for recycling, you still need the disposal solution. And this is the example that ANSTO is facing in the return of the high fire fuel to Australia. You still have to dispose of the residuals.

MR HANDSHIN: Can I ask Mr Voss, in relation to the first stage, the storage, what sort of - - -

MR VOSS: Yes.

MR HANDSHIN: - - - timeframe is involved in that first stage?

MR VOSS: I'm not quite sure which timeframe you are referring to?

MR HANDSHIN: Sorry. The initial stage of storage, be it wet or dry. How long do you need to store the material like that for?

MR VOSS: I would – I am going to answer a slightly different question. You don't need to store it for any period of time in an engineering, scientific, health and safety sense, but when you move it off a reactor site it has probably been out of the reactor for five years or so. You want that degree of radioactive decay to have occurred. If you choose to reprocess it then or dispose of it then, you could. So the need, in my opinion, is - there is no need to store it longer. The need, in my opinion, is driven more by the question of how long will it take to get an acceptable disposal path in place.

Turning the question a little bit differently is how long can you store it, and the answer to that is many, many decades, many, many decades, 100 years if that's what you chose to do. Here in the United States we're working with specific parties right now where we are anticipating that spent nuclear fuel will be in storage for at least 100 years, and none of these are particularly challenging from health and safety environmental protection standpoint. The fuel is very, very robust. The containers in which you put it are an added layer of safety and protection, and then of course the storage casks themselves are yet another.

MR HANDSHIN: With the long-terms solutions for disposal, can that be both artificial and natural disposal facilities?

MR VOSS: I'm not sure what you mean by an artificial disposal facility.

MR HANDSHIN: An engineered facility?

MR VOSS: This gets into a philosophy of confidence, actually. Spent fuel has to be contained for a very long period of time to be inert or move past an acute hazard level. My view is that that time needs to match up where the material in disposal begins to look like a uranium deposit, because we have those all around and we know that those are like. Now, that containment period is hundreds of thousands of years. So I have two choices. My preference is to go into a piece of geology where I can prove that the geology has been static for millions of years and rely upon the natural stability of that structure to contain it. If something has been stable for 5 million years and I need to 200,000 more years of stability, unless there's some evidence of some mechanism that's going to overturn that, then you start with a geosphere that it inherently safe.

Now, there are others who believe that you need to then add to that what is referred to as engineered barriers. In Sweden, for example, where they don’t have that geologic stability in place, they're going to an extremely expensive multilayer engineered barrier disposal facility. Whether or not that is needed in that environment, they believe they need to do this. I personally have a bit of a problem with this. If I have a geosphere that is extraordinarily robust, then are you kidding yourself when you say, "I'm going to build something that will also last 100,000 years?

But having said that, the key part of this is again the social contract. Every successful nuclear endeavour is successful in part because there is a regulatory infrastructure in place that the public trusts, and this would be equivalent to food safety or anything else. If that regulatory infrastructure in Australia said, "You must have engineered barriers in addition to your geosphere," then that's fine. That's what the regulator is demanding and that's what's needed. It doesn't mean I personally think it's the right thing to do, but so be it.

COMMISSIONER: Can I perhaps move off into - you've done some very broad analysis of the opportunities if the nation agreed to store spent fuel.

MR VOSS: Yes.

COMMISSIONER: Can you just broadly outline what you see as those opportunities and how much modelling work you've actually conducted to get to those conclusions?

MR VOSS: In our submission, we delivered some work that was done 18, 19 years ago, and those have been updated in some work that I did, I believe, two years ago. When I look at the uranium export in Australia and then I look at the economic opportunity, rather than turn to my own speculation of pricing I found citations in the literature, and I believe the citation that was attached in our submission was an OECD NEA document which looked at the estimated financial commitment by nuclear utilities for waste management. Using that number as a financial opportunity led to the very specific projections that were made within our submission.

There are two major presumptions in that: one is that the marketplace is there, people would actually sign into contracts; and the second presumption is that the OECD NEA projection of commitments for nuclear fuel management are accurate. Our own view is that those projections are accurate based on, you know, sort of rules of thumb from other data sources. I'm not going to throw numbers at you, because I don’t have them at my fingertips here, but again, they're in the submission you're looking at right now.

COMMISSIONER: As I see just briefly going through it, you thought that it could lead to a direct increase of 8,000 permanent jobs.

MR VOSS: That's correct.

COMMISSIONER: That was the sort of ballpark figure that you were working from.

MR VOSS: Yes. In my past in Pangea, commissioned work from Access Economics in Canberra to examine the macro-economic impacts of these sorts of functions and activities and those numbers were updated in some research that I did two years ago and submitted in the (indistinct) submission. But, yes, it's many thousands of permanent jobs and of course they're during the construction phases of these facilities. There's obviously increases in the construction side. Most of these jobs are driven by this industrial infrastructure that I mentioned, the ship building, cask building, and most of those jobs end up being blue collar, union jobs of highly skilled men and women to construct these facilities and ships. There is obviously a white-collar component of employment that comes out of the business safety – the entire corporate structure that is around this. Our crystal ball isn't quite strong enough for me to tell you it's - of the 8,000 it is 1,500 white collar and 6,500 – I can't look that deeply in to the matter.

COMMISSIONER: No, that is the ballpark figure that I was seeking to establish. One of the concerns for the community and one of the concerns that we must address is the safety of the operation.

MR VOSS: Yes.

COMMISSIONER: Can you work through why you are confident and why you are confident in your submission that the safety aspects of managing spent fuel for hundreds of thousands of years, can be managed?

MR VOSS: There are – let me break this in to two pieces. The piece prior to – everything prior to actually putting spent fuel in to the ground and then once it's in the ground. Now I have referred to the point of the geosphere and the isolation that that geosphere provides once it is in the ground. I believe a regulator should establish an extremely aggressive or restrictive risk standard and that nothing should be put in to the ground until that risk standard is unarguably met. That it is demonstrated and that is the safety that is in disposal. I believe it can be met because of the extraordinarily robust geosphere that exists in many parts of Australia. Now that – if I can really leave that assertion apart for a moment, then you get in to the front end of this. There is an extraordinarily robust safety record for the handling and management of spent fuel worldwide. This is taken with great seriousness. There must be, from day one, a culture of safety that starts at the chairman's office and goes through the entire operation but that is what does exist in the nuclear industry.

But beyond that, every part of the safety culture presumes that you are going to have an accident and it presumes that if that accident occurs, that you know exactly how you are going to contain the nuclear material and how you are going to clean it up and how you are going to recover and how you are going to repackage things. You know there are many thousands of nuclear packages shipped every day worldwide, pharmaceuticals, radioactive waste, an enormous amount of stuff. In the area of spent fuel, there are no accidents from that. This material is handled as if it were gold and is handled with great seriousness. I have complete confidence in the infrastructure and the experience and the facilities and the people to do that but for the public to have confidence of that, what we would – a) as a I said a moment ago, we would need a very aggressive and tight regulator to give the public confidence that we are regulating and managing it correctly but that culture of safety has to start on the first day and be carried through forever.

MR HANDSHIN: Can I just raise one safety related matter generally, and that concerns the topic of non-proliferation? How do you see - - -

MR VOSS: Yes.

MR HANDSHIN: - - - fuel leasing arrangement interacting with non-proliferation concerns?

MR VOSS: I think it's a great complement to the non-proliferation objectives. If Australia owns the nuclear material that is being used in a reactor and – okay, it can't go over by force and actually recover it but there are many other entanglements that become very significant. If somebody is taking Australian fuel and decides to break in to it and try to recover nuclear material out of it, well Australia is actually holding the fuel that is needed for them to generate power. This is a very significant lever tool in controlling this material. So I think it fits absolutely perfectly with the non-proliferation objectives that every nation must have.

MR HANDSHIN: I just have two more questions Mr Voss if I may? The first is whether the concept of fuel leasing, as you have described it to us, has ever been employed anywhere in the world in the past?

MR VOSS: No.

MR HANDSHIN: And that might - - -

MR VOSS: I am sorry. Let me back up – let me back off that a little bit. Just to be clear, it is a little bit difficult for me to say the Russians do undertake or the Russians do not undertake it. There have been arrangements with some of the reactors that the Soviet Union deployed in the former Soviet countries. There are discussions that under the Rosatom agreements with Vietnam and Turkey and those that they are proposing in Argentina, that they will take material back as well. Now that goes well past however, and I am strictly speaking here about what the trade press is reporting, this goes well past fuel leasing as we are presenting it to you. Because in those cases, the Russians actually own the nuclear power plants and operate them. So the Russians are sort of taking – appear to be taking the view that this is not leasing the fuel per se, but this is Russia building a plant in another country and running it and taking the material back. So that is, to answer your question, the closest that we are aware of.

MR HANDSHIN: Is there any reason that you can see why the concept of fuel leasing, as you have described it to us, hasn't been used in the past?

MR VOSS: Yes. Because no country would put their hand up and say, we'll take the material back.

MR HANDSHIN: So that goes back to that foundation or social contract issue that you have spoken about?

MR VOSS: That's correct. By the same token, the – using the Emirates as an example and the Swiss, both have provisions with international law that say we will allow our nuclear fuel to go elsewhere for management, however it must meet a certain set of very restricted conditions.

MR HANDSHIN: So compliance with those conditions would be a precondition to any fuel leasing arrangement with those countries?

MR VOSS: Exactly.

MR HANDSHIN: The only other question I had Mr Voss was whether it is possible to give us some idea of the cost that might be involved in setting up the fuel leasing arrangement, as you have described it to us?

MR VOSS: My opinion is there would probably be about 100 million on the front end. And I am not going to argue whether those are AUS dollars or US dollars. There is an enormous amount of front-end work that has to be done before the first contract is entered in to. From an investment standpoint, you know you would have structured this thing as a series of gates and you would ask for equity to get through the first gate and if you did, then equity to get through the second gate and so forth.

MR HANDSHIN: So that figure is just a ballpark figure?

MR VOSS: Absolutely. There is no science to that figure whatsoever.

MR HANDSHIN: Thank you.

COMMISSIONER: Mr Voss, thank you very much for your evidence this morning. We very much appreciate you taking the time to talk to us.

MR VOSS: I am grateful for the opportunity. Thank you.

COMMISSIONER: Thank you. We will adjourn now until 11.15.

ADJOURNED **[10.50 AM]**

RESUMED **[11.45 AM]**

COMMISSIONER: Welcome back. Reconvened, 11.45, and I welcome

Dr Michael Goldsworthy from Silex. Counsel.

MR HANDSHIN: Silex Systems Limited is an Australian public listed company which invented and developed the disruptive laser enrichment technology known as separation of isotopes by laser excitation, or SILEX. Silex is continuing to support the commercialisation of SILEX technology for the global uranium enrichment industry in conjunction with exclusive licensee US-based GE Hitachi Global Laser Enrichment. Dr Goldsworthy is the founder and managing director of Silex. He received his PhD in physics from the University of New South Wales in 1988. Apart from the nuclear power industry, Dr Goldsworthy has also had extensive experience in the semiconductor and solar power industries through the business activities of former Silex subsidiaries, Translucent, incorporated in the United States, and Solar Systems, both recently divested.

COMMISSIONER: Dr Goldsworthy, we might just slowly march through broadly what Silex is, the history of its development and then a little more detail about where it fits into the conversion cycle, and then we'll talk about commercialisation and application to the South Australia. So perhaps you might just start with a kind of brief history and a bit of an overview of the technology.

DR GOLDSWORTHY: Sure. So the company was started in 1988 as a subsidiary of Sonic Technology, as it was known then. We get funded on a shoestring budget. I did some work in the early 1990s with another scientist from the ANSTO laboratories. As soon as we made ourselves known, we were snaffled up by the Australian Safeguards and Non-Proliferation Office and we were quarantined pretty early on into the Lucas Heights facility. We worked in the early years just on conceptualising different processes, looking at AVLIS and MLIS. There was a lot of activity back in those days on other technologies around the world.

In the first half of the 1990s we actually did some experimentation in Lucas Heights. We started to uncover some interesting effects, if you like, benchtop laboratory experiments, very small scale, and by the mid-1990s we thought we'd identified a path that was different to AVLIS and MLIS, addressed the issues that those sort of technologies had, and then moved forward in the next five years or six years with a company called Uset. They came onboard and funded us for a few years in the late 1990s. We progressed the technology. They were actually funding a big program for AVLIS at Lawrence Livermore Laboratories in California.

COMMISSIONER: I might get you to explain what that is.

DR GOLDSWORTHY: Sure. So they were actually looking at three technologies at once in the late 1990s. There was the SILEX technology, the AVLIS technology, which they'd inherited from the Department of Energy in the United States, and then there was also American centrifuge. Come the late 1990s, I think it was about 1999, their board decided, "We've had enough of laser." AVLIS wasn't working the way they wanted it to. It was not showing the economics that it needed to. So they disbanded the AVLIS program in 1999 and that had probably $2 billion mostly of US government money spent on it. They spent a few hundred million dollars. And they also withdrew their support of the SILEX technology and they decided to go for American centrifuge and focus solely on that.

In the early 2000s we did what we call a direct measurement program. This was now after Yousef departed. We probably did our best work then. We had built a lot of equipment that was partially scaled up at Lucas Heights and we had some very impressive results in those few years, 2002 to about 2005, 2006. So we actually put in concrete our process. It wasn't a concept any more. We demonstrated actual enrichment for the first time in those years. In other words, we weren't just looking at analogue molecules or looking at signals uranium.

On the back of those results we attracted three overseas companies to become our licensee, our new licensee. We had a bit of a competitive process and in early 2006 we decided to sign the agreement for the licensing of the technology to General Electric. In 2007 they brought in their nuclear partner, Hitachi. So GE Hitachi formed a subsidiary called Global Laser Enrichment. In 2008 they brought in Cameco, one of the world's largest uranium producers, into the GLE consortium. So that's the structure we have today. The licensee is Global Laser Enrichment which is still a subsidiary of General Electric. General Electric has 51 per cent, Hitachi has 25 per cent equity in GLE and Cameco has 24 per cent equity. So they have been funding most of the program until the present day from 2006.

In 2007 we actually moved the technology to their site in Wilmington, North Carolina. The US government was very keen to take the technology to the US and safeguard it there. We also kept a small effort going in Lucas Heights and that is still happening today. This is focusing on the core laser technology for commercial plant systems and we've made solid progress. In fact, we recently demonstrated an integrated plant laser system at commercial rates and that's a huge milestone we've just passed with the laser technology. When we compare our technologies to AVLIS and MLIS3 one of the big problems with particularly MLIS was the laser technology. A lot of people thought that laser enrichment was beyond laser technology.

COMMISSIONER: It might be a very opportune time for us to explain exactly what we mean by this laser technology. I think we've got a slide so we can look at the flow diagram.

DR GOLDSWORTHY: Yes.

COMMISSIONER: Perhaps you can run us through this.

DR GOLDSWORTHY: What we have here is a basic block diagram of the SILEX process. On the left-hand side we have the two inputs which is the uranium hexafluoride feed. I'm sorry, the labels have dropped off this slide and we're on the next slide. The two arrows on the left, the top one is uranium hexafluoride feed and the bottom one is the carrier gas feed. Those two gases are mixed in the feed system and they pass through what we call a separator. Also passing through the separator is the laser beam that does the enrichment. Those two block diagrams in the centre, coloured pink on this screen, that is the heart of our intellectual property. That is the heart of the SILEX process. That differs to any other process that has been proposed in the past for laser enrichment, including AVLIS and MLIS.

There are support systems on the bottom line coloured in yellow. These just provide the support and recovery and storage. So we've got three colour codes. The green is essentially the same process systems that are used in a gas centrifuge plant. The yellow are known technologies but adapted to our process. The two pink boxes are the heart of our SILEX technology intellectual property.

So the feed stream passes through the separator. It's a mechanical system with optical engineering apparatus that makes the beam do what it's meant to do to the uranium hexafluoride gas. So the gas flows through the laser beam. The laser excites the desired isotope and leaves the other isotope unexcited. From there we have a process to extract the excited species. Now, the technology is classified. So I can't go into details.

COMMISSIONER: That's fine. We wouldn't understand it anyway.

DR GOLDSWORTHY: A fair bit is known about molecular laser isotope separation which this is closer to than AVLIS, the atomic vapour process. So there are some similarities with molecular but there are fundamental differences between the SILEX technology and the MLIS technology which we can't go into today. Once the laser has achieved what we call discrimination between the two isotopes then the excited or the desired isotope is separated in the product stream, which is the top right-hand flow arrow, and the tails stream, which is the leftover which is now depleted in the uranium 235 isotope, comes out as what we call tails, depleted tails. So that is how we do the SILEX process for laser enrichment. The key thing here is that a lot of the plant, a lot of the technology, is already in existence. A lot of it is adapted from known technology, the yellow. The pink boxes are where we are busy working today.

If we go to the next slide we can see where we are today. I think it's just clear enough. You can see the laser systems are a hatched colour of pink and this is mostly demonstrated – as I mentioned just a little while ago, we have now demonstrated an integrated commercial plant laser system at Lucas Heights for extended periods. We've accumulated hundreds and hundreds of hours of operating experience with that laser system. It has been optimised for a plant application. So the laser systems are quite advanced in terms of being ready for commercial deployment in the future. Separator systems are a little bit behind the laser systems. We've had a lot of work over the years on the separator system. There's a lot of technology and a lot of innovation in the separator systems but we don't see any issues with – it's an engineering effort and that's going to take time and effort.

What happened because of the market situation – the nuclear industry, as you've no doubt learned, has fallen into difficult times post-Fukushima. Some countries are opting to move away from nuclear power. Others are closing plants early and, of course, Japan itself has had all its reactors off until the last two months with the first reactor in Sendai coming back online and, interestingly, the second Sendai reactor coming back online today, I believe. This has created a very difficult market for uranium production and for uranium enrichment. So the licensee, GLE, our licensee, decided to slow the program down last July in sync with the adverse market conditions. So the effort on separator systems was slowed down significantly at that point.

All in all we are making good progress through what we have. We have a staged date program. We have three phases. The first phase was demonstrating the technical ability, technical validation of the technology. That was completed in 2013. The second phase which we are in now involves engineering scale-up to full commercial scale and economic validation. So we've finished or pretty close to finishing the laser systems and we're well down the path in scaling up the separator systems. So that's where we are today. In terms of time, I don’t know if I should go into the timing, what we expect now, or not.

COMMISSIONER: We might go and do that a little bit later. We certainly want to get to that.

DR GOLDSWORTHY: Sure.

COMMISSIONER: I'd like to crystallise firstly the difference between SILEX and the current methodology. I think you've got a slide on that. This is the centrifuge.

DR GOLDSWORTHY: So centrifuge supplies most of today's enrichment. About 86 per cent of today's production is using centrifuge machines of one form or another. There's about 14 per cent of enriched uranium still being supplied from what we call secondary sources that would include inventories that have been held over from gas diffusion production in France and America, The use of reprocessed uranium, the use of mixed oxide fuel, MOX fuel. There's a few other minor sources of secondary material. There is still some blending down from warhead material in Russia as well. And I think the US is proposing to blend down some more. But by and large, most of today’s enrichment is done by gas centrifuge machines, of the type that you see here. I believe this is a Urenco Cascade Hall. So there is four suppliers today, key suppliers, big suppliers. There is the Urenco Tri-partite Organisation based in Europe but now also has a plant in the US. There is Areva which has now also become a user of the Urenco centrifuge under an agreement with Urenco then there is Tenex, the Russian company which uses a Russian centrifuge, much smaller and less efficient than the European Urenco centrifuges. And then there is the Chinese – China Nuclear Fuel Corporation which is part of the China National Nuclear Corporation CNMC. CNFC has now rapidly built up some centrifuge capacity in China for domestic supply of enrichment. And they are saying they are going to keep building supply in line with their expansion of nuclear power.

So we are down to four big players in enrichment. It is a very, if you like, closed industry, very little competition, if you like. It comes out of a military background, the Cold War era. Centrifuge itself was invented during the 1940s or thereabouts and has progressed quite slowly over the years in terms of development. They have just about squeezed everything they can out of the centrifuge machine now, especially Unco/Areva. They are up to what they call TC12 which is a 12 generation centrifuge machine. Successive generations have squeezed a little bit more efficiency out of this concept which essentially uses a spinning rotor to spin the UF6 gas. What happens is centrifugal force forces the heavier particles to the periphery and the lighter particles tend to stay towards the centre and those slightly differentiated streams, only slightly, the measurement factor is only 1.3 or 1.5. Those slightly differentiated streams of gas are separated physically and moved to a successive stage of enrichment.

COMMISSIONER: Where it is done again?

DR GOLDSWORTHY: It is done again. It is a very repetitive process. It needs dozens of steps, individual enrichment stages in successive centrifuge machines and so it is a modular successive process to get from .7 to about three to five per cent.

MR HANDSHIN: Could I just talk about supply versus demand? You talked about four suppliers. At the moment, the capacity in relation to demand is – is it oversupply?

DR GOLDSWORTHY: Nameplate capacity is in excess of current demand, that is particularly now that the Japanese fleet is off line. But if the Japanese fleet was still on line, there would be a nominal excess of capacity still. That is – how bit that is, is still a matter of debate. The Russians and the Chinese don't tell anyone how much capacity they have got exactly but we believe it's – there is probably a few million separative work units of capacity beyond what the market needs today. There has also been some shutdowns in different parts of the world that have exacerbated the imbalance between supply and demand in the last few years. But essentially there is a study – we follow the analysis of the market specialists, UX Consulting, TradeTech, World Nuclear Association and they all show that the scenarios going out 10 to 20 years from today, taking in all factors, including the Japanese situation, all the reactors being shut down, new reactors being built, possibilities of trade sanctions with the Russians and the pace of restarts in Japan.

So they have all painted a difficult period over the next five to 10 years for both the uranium and the enrichment industry. They have said that we will be in an excess supply situation and with inventories to be taken up over the next five to 10 years, that will not see the need for new capacity for uranium enrichment, possibly as late as 2030, or certainly maybe 2025. So from today, we're looking at a situation where even with our technology we don't know exactly when the market will be ready for new capacity to be built. Of course we would like it to be Silex Technology but we don't know whether it will be the mid-2020s, the late 2020s or even out to 2030 before the market is ready for new capacity.

COMMISSIONER: And do you see, this perhaps leads in to the next slide, do you see your potential for your technology to replace existing capacity, or to replace it when it's retired?

DR GOLDSWORTHY: Yes, that's an interesting question. The way centrifuge plants are run, because they are so modular, each machine develops maybe 10 or 20 SWUs, maybe the Russians are less, maybe the Europeans are more. Having thousands and thousands, maybe 10,000 machines in a plant, they have inbuilt redundancies. So if a particular machine fails, they just pipe around it, valve it off and pipe around it. That has been the way they've worked for some decades now. There is a natural attrition rate but the plants are flexible enough that they can operate with an attrition of centrifuges. Now as we move forward in this situation with - apparently the analysts are hearing that – in fact, I was at a conference last week in Colorado, the Nuclear Fuel Conference, and the Urenco people were saying that they probably will retire some capacity earlier than planned previously because of the current market situation. So to your question, I don't think we're going to replace centrifuge capacity but we could see some older centrifuge capacity shutting down earlier than previously planned which may open the window a little bit wider for us. But what happens is a centrifuge plant is built and started up and those centrifuge spin until they die essentially.

They can't stop a centrifuge plant because the market's not there; they have to keep it spinning. For technical reasons, it's very difficult to restart a centrifuge machine. In fact, it's very difficult to start them up the first time, even more difficult if they have been used and full of material. So they go through what we call resonances, the machines can fail through some of these resonances. They go super critical, which means the outside of the rotor is going beyond the speed of sound. But essentially, these machines are very finely balanced; they go through according to what I heard last week, a dozen different resonances as they go higher and higher speed. They spin at anywhere between 60 to 80,000 revs per minute which is quite fast and some of them don't make it through those resonances, as they work up to speed. So they cannot shut them down, they keep running them at the operating speed. In other words, those machines – those plants are still producing enrichment day in, day out even with this market in a pretty poor state.

COMMISSIONER: Hence the over supply?

DR GOLDSWORTHY: Over supply and they've what we call underfeeding those plants. So they are doing more enrichment on less speed and so they are getting less, they are getting more depleted tails.

COMMISSIONER: Yes.

DR GOLDSWORTHY: And the same amount of product but less material is going through and so under feeding means that they are effectively conserving natural uranium, they're not using as much. So that is going to back up in to the uranium market for some time yet and then as they keep under feeding there will be still some excess enriched uranium that will go in to inventory until the Japanese situation corrects and until other countries start building again.

COMMISSIONER: Perhaps we could just look at the comparison that this slide shows and perhaps you could walk us through the bits that you haven't explained and the enrichment efficiency? Can you explain - - -

DR GOLDSWORTHY: Sure.

COMMISSIONER: I think the first part we understand.

DR GOLDSWORTHY: Yes. So enrichment efficiency is the single stage enrichment factor. So if you have .7 feed material, roughly, going into a gaseous diffusion stage - - -

COMMISSIONER: By .7 you mean - - -

DR GOLDSWORTHY: .7% natural assay.

COMMISSIONER: Okay, yes.

DR GOLDSWORTHY: .7% natural assay of 235 going into that stage. You'll get 1.004 times .7% coming out in the 235 isotope. So gas diffusion is notoriously inefficient. It was built at the beginning of the Cold War for military purposes essentially, and it was turned over to commercial production in the late 60s and 1970s in Europe, Russia and the USA. Centrifuge is a lot more efficient. So if you have 1% material going into maybe the second stage, it'll come out at 1.3% 235 or 1.5% 235. So that's the factor of enrichment multiplication of the 235 isotope.

With laser being a classified technology, we have a rule book called the Classification Guide and the way we've described the enrichment efficiency is dictated by our classification guide. We have to describe it as a low to high range, and the difference between those two numbers has to be ten or more. So this is the best we can do. We can't tell you how close to two or how close to 20. All I can tell you is it's above two and it's below 20.

COMMISSIONER: All right. That's what we work with.

DR GOLDSWORTHY: I can say it is a lot more efficient than gas centrifuge, because we're using laser excitation of the UF6 molecule, which is not trying to work on the slight mass difference in centrifuge and gas diffusion. So what we do, these molecules have optical absorption bands that can absorb different types of light. In the case of molecules where we're dealing with UF6, it can absorb a photon of infrared light from the laser at the precise frequency that creates a different vibration inside the molecule. So it's called a vibrational excitation using the laser photon.

COMMISSIONER: Would the next slide help in that description?

DR GOLDSWORTHY: Yes. Actually the example used by Nature News in this slide is actually for AVLIS, the same principal but it's now at the atomic level. So instead of having a molecule that you're trying to absorb a photon to create excited vibration, AVLIS uses atoms of uranium and the laser light is tuned to an absorption that creates an excited electron stage because it's an atom. And so AVLIS works on atomic excitation, MLIS works on molecular excitation, but in both cases the laser is finely tuned to that precise jump that gives either the electronic excitation or the vibrational excitation, and it's so precise that the other molecule that contains the 238 atom, or, in the case of AVLIS, the 238 atom, is transparent to that wavelength of photon, and so you get very high discrimination effects from the use of lasers as opposed to the mechanical systems, and so that gives laser a clear advantage in much higher efficiency and, hopefully, lower cost.

COMMISSIONER: I think we might rest there. I want to come back to commercialisation in a minute, but I'm sure counsel has some questions.

MR HANDSHIN: Yes. I think, Dr Goldsworthy, so far as the comparison was concerned on the slide that’s currently displayed, we got to the level of cost comparison. I wonder if you could talk us through that.

DR GOLDSWORTHY: Okay. So I included the next slide for that reason. It's very hard to find out precisely what the costs for enrichment are using these different systems, but this article did try to estimate the costs. Obviously they interviewed the sources and Nature is a reputable science journal. So the reason I put this in was because you have some estimates of the costs for first generation diffusion, second generation centrifuge and third generation laser. The laser is based on AVLIS, but it's still a laser technology. So what I can say is, GLE has a policy of not divulging market-sensitive information such as costs because we don’t want to be disadvantaged in the market by people claiming, you know, that we're producing at less cost than we are.

Anyway, the point of this slide is to give you a ballpark comparison of the costs of these three generations of enrichment technology. I don’t think they're far from reality. Maybe $30 for the AVLIS laser technology per SWU is a little aggressive, but I think it's in the ballpark. Mind you, AVLIS hasn't been commercially deployed ever. But as far as our costs go, we are a laser technology. We would expect to be a significantly cheaper cost than gas centrifuge, second generation technology. So we think this is a good example of the ballpark costs for these three generations of technology.

MR HANDSHIN: One other point of comparison that arises concerns the management of tails and I think you mentioned that at the start of our discussion. Can you elaborate on that at all?

DR GOLDSWORTHY: So all enrichment processes produce an enriched product stream and depleted tail stream. Depending on the efficiency of the technology, you can - and this depends on what the utility wants as well in terms of product assays and tails assays, because they actually own the uranium when they take it to the enrichment company. But generally speaking, the optimal - if there were no other external factors and it was an ideal market and demand was a little bit ahead of supply, each technology has an optimum tails assay and in fact with centrifuge you really have to build it close to the optimal tails assay, and my understanding is that the Urenco and Ariba type plants are built to produce depleted tails assays of around .2 to .28% of 235 isotope, somewhere in that range, .2 to maybe .3.

To go outside that range, they become less efficient and they have to rearrange the plumbing to their cascade configurations, and for laser systems, because we have a more efficient technology, we can actually configure to go to lower tails assays, and remember I talked about underfeeding before. If you produce lower tails assays you can put less feed through to obtain the same amount of product. I'll use an analogy which I heard some years ago and I thought it was a very good analogy. It's a bit like getting orange juice out of oranges and there's a synergy between the effort of extracting the orange juice to how much the oranges cost, which is parallel to the relationship between enrichment of uranium and production of natural uranium.

So if oranges are cheap, you dial down your squeezer and you squeeze a bit of juice out and you throw away the rest of the orange still with a bit of juice in it, quite a bit maybe. If the orange is cheap, why not? Just throughput. If the orange price goes up you dial up your squeezer. You try and extract every last drop because your oranges are costing more. So that's the dynamic between uranium production and cost of uranium and the cost of enrichment. If uranium prices are down, then they will overfeed. They'll optimally produce high assay tails because uranium is so cheap. So that's what happened in the 70s, 80s and 90s. Uranium was quite cheap and so, particularly with diffusion plants which are not very good at stripping anyway, a lot of inventory of tails was built up around the world, including the United States, of what we call high assay tails. So they were effectively overfed.

As uranium prices went up, centrifuges in particular did more separative work on less feed, and so extracting more of the good isotope out from less feed, so in effect conserving uranium, and this is a dynamic that has been quite interesting in the modern market between uranium pricing and enrichment pricing, and now it's all been twisted and messed around because of the situation since Fukushima. It's even more complicated. In fact, as I said before, it has become somewhat twisted in that centrifuge companies have had to keep maintaining full capacity and that has stilted the market even further.

So overall there's a lot of dynamics in the marketplace between uranium prices, enrichment and the type of enrichment technology but laser being so efficient, it can strip tails much, much more efficiently than a mechanical system, whether it be centrifuge or diffusion. So we do have an advantage in, if you like, conserving uranium in the future when uranium prices go up again, because one day uranium prices will go up. It's a finite resource, cheap. It will be finite. It will go up. So there will be more demand on extracting every last bit of goodness out of every kilogram of uranium that goes into an enrichment plant in future years. So laser will have an advantage in terms of producing low assay tails.

If we flip that around – what I mentioned in the 70s, 80s and 90s was the production of high assay tails. The first opportunity for our technology with Globalised Enrichment looks like being a tails reprocessing plant in Paducah, Kentucky. This has come up since about 2012. It's the site of the last operating diffusion plant in the world, in Paducah, Kentucky. The US Department of Energy requested proposals and GLE was exclusively selected. The proposal involves building an enrichment plant with the SILEX technology specifically designed, configured slightly differently to a normal enrichment plant, to reprocess those high assay tails from .3 to .4 per cent back up .7 per cent, 235 assay which is natural grade.

So that plant will be akin to a uranium mine. So they're going back in and mining all the old tails inventories. There's hundreds and thousands of tonnes of inventories in America alone that can be reprocessed with an efficient technology to bring that material back up. About a third of it will become natural grade and the two-thirds remaining will be even lower depleted tails. It will be .1 to .15 per cent tails. So that's, if you like, extracting further value from a resource that probably was written off 20 years ago.

That's what I've alluded to in our full submission to the Royal Commission, that South Australia is blessed with huge resources of uranium but we don't want to underestimate the value of the depleted tails either. Not only can we extract more value for a normal light-water reactor with enriched uranium by conserving that uranium but we can also keep the remaining tails, the low assay tails, for future generations of reactors, again generation 4 reactors, some of which will use depleted uranium or natural uranium. They're called breeder or vast-spectrum reactors. They are on the horizon. They're not that far away now. I know that GE Hitachi provide a submission with some information on their prism reactor. There are other fast neutron reactors that will use the other uranium that light-water reactors don't use.

So we don't want to underestimate the value of the remaining 90 per cent of the uranium that doesn't go into today's reactors. It's a valuable resource for the future and it's not that far away. If we have an indigenous enrichment industry, we keep that material here for future use. If we don't have that indigenous enrichment industry, the whole lot goes offshore and we get nothing for it, no value.

MR HANDSHIN: Can I just ask one more question in the context of this comparative analysis. We've heard some evidence today and the Commission has received other materials that draw a connection between all enrichment processes and proliferation risks. Can you tell us where laser enrichment fits inside that topic?

DR GOLDSWORTHY: Interestingly, the slide that we decided we would put up, we don't agree at all with the rating of the proliferation risk. We talked about this on the phone the other day. There's three factors here. There's a historical factor, there is a raw comparison of the two technologies, centrifuge and laser enrichment, and there is also the issue of nonproliferation safeguards and custodianship of these technologies. So to the first point, the history of uranium enrichment, obviously with diffusion there was, if you like, no leakage. These plants are monsters of plants. They cost a huge amount. Not even the US government could afford to build a diffusion plant today.

Centrifuge is today's technology and historically it hasn't been a good story with proliferation. We've had numerous cases where centrifuge technology has been leaked outside the core custodians of that technology and in particular the most widely known case was the A.Q. Khan case, the Pakistani engineer who worked for Urenco and leaked the secret designs to the Middle East. There have been other cases of leakage of centrifuge technology.

Now, I'm drawing your attention to the weakness of centrifuge technology in terms of proliferation risk because it is fundamentally a simple technology. It is a spinning rotor. Yes, there's a lot of technology now in the bearings, whether they be magnetic or air bearings, and there's a lot of technology in the rotor designs and the structural integrity of the rotors to get them through these resonances and to keep them spinning for two or three decades. But fundamentally you don't need a generation 12 Urenco centrifuge to enrich uranium. You can use a Pakistani generation 1 centrifuge. You can use a North Korean generation 1. These machines can be back-engineered relatively simply and I think that's the biggest challenge for the nuclear industry or the proliferation regulators today, is to keep a watch of centrifuge technology.

The second factor is comparing centrifuge with laser. The technical barriers to achieve laser enrichment are enormous. It's my whole working life so far and we're still not commercial. I've been at this for over 25 years and we've had some of the best brains in the world working with us from the US and from South Africa and of course Australia and we still have some years to go yet. This is in the context of billions of dollars being spent around the world on AVLIS and MLIS, the two other laser enrichment technologies. All through the 1970s, 1980s, 1990s and now into our era literally billions of dollars were spent on trying to achieve effective laser enrichment. Whilst at pilot level AVLIS was demonstrated, I don't think MLIS has ever been demonstrated at pilot level. There are always these fundamentally huge technical barriers to achieve laser enrichment compared to centrifuge.

I think if you're a proliferator and you stand back and say, "What path am I going to go down? Centrifuge or laser," if all you want to do is enrich uranium for maybe not the right purpose, history shows you would choose centrifuge. That comes from a raw difference in the accessibility and availability of these technologies. So our view is that laser enrichment is way more difficult to achieve. It's proliferation risk profile is much less. There are many more components of a laser enrichment plant that you can try and keep track off, in fact they do keep track of. There's laser optics components, there's laser switching gear, very sophisticated electronics gear which is regulated. A lot of the devices and components on our bill of materials is regulated by the US government today. Well, we're based mainly in America and Australia of course.

You can keep watch of these key components. They have what we call signatures. So we can get a pretty rapid idea of if anyone is trying to replicate laser, and we do. They have detected Iran was doing some laser work. They have detected the North Koreans tried to. But there's a wall of difference between trying and achieving. So we are now nearly there but, of course, heavily regulated, heavily monitored. We're still not quite there.

COMMISSIONER: That might be a good time for us to go and understand GLE’s approach to commercialisation of the technology. Can you walk us through the approach that you are taking and what has been achieved to date? And what the next challenges are?

MR GOLDSWORTH: Sure. And the approach has been thrown in to turmoil with the recent market conditions but we are undertaking a phase gated development, or commercialisation programme which is shown in one of the other slide and on our website. As I mentioned, phase one which was six, seven year programme that concluded in 2013 was to provide technical validation of our technology. In other words, show at a reasonable scale that it enriches uranium efficiently, as represented by us originally. That was done – that was completed in 2013. The second phase involves economic and engineering validation. So the first phase of only partial scale, now we are moving to full scale equipment, full scale that would be put in to a commercial plant, lasers and separators and support systems and then running that equipment in what we call the initial commercial production module. If you like, a pilot plant. And then, providing all the data we need to determine the full economics, including the reliability of all the componentry and equipment and in the meantime, between failures there is an exhaustive process to go through yet before we get to a point where we say we know how to build this plant. We know what it will produce in terms of economics for enrichment.

So this is the second phase, then the third phase is when we build that first commercial plant, which now looks like it will be that tails reprocessing plant in Paducah because the enrichment market, I don't think is going to be ready for us maybe for another decade at least at this point.

COMMISSIONER: So phase two, you consider is a decade away yet? Complete for - - -

MR GOLDSWORTH: To complete – well, it depends on the funding because we've had a pretty significant cut in funding, as of July last year, because the market isn't there. So - - -

COMMISSIONER: Okay.

MR GOLDSWORTH: - - - at the current funding level and maybe a little more, we are probably looking at three to four years to finish phase two.

COMMISSIONER: Yes.

MR GOLDSWORTH: And probably another three to four years at a slower rate than we might have proposed earlier to build that first plant; maybe that Paducah plant. So we are probably looking at six to eight years from now to be in production for the first plant if the plant at Paducah goes ahead, and there are still a lot of ifs and buts because the uranium price is also very low and so this plant will produce you natural grade uranium, it will be sold in to the uranium market but we need to see a better price than today's uranium price, to realise the internal rate of return that the investors need; the three shareholders of GLE. So that is broadly speaking, the timeframe, if the market comes back to us. If the market comes back more aggressively, we could accelerate that timeline. If the market stays in the doldrums for even longer than the analysts are predicting then we won't even be there then. But how soon could we be ready? Looking from a South Australian perspective, if we really wanted to be ready earlier, we could be ready in that six to eight year timeframe, maybe a bit earlier but that is the sort of timeframe that is reasonable at this point of time.

We don't get in to the habit of detailing timelines to finish phase two or get in to production but I think it is important for the Royal Commission to understand the timeframe that we might be available to partake in an enrichment plan here.

MR HANDSHIN: Mm. And how and why would South Australia be a suitable place for a Silex facility and what would the pathway towards that – establishing that kind of facility here be?

MR GOLDSWORTH: So two key points on the first part of the question is that obviously the amount of uranium in South Australia is enormous, it's a third of the world's uranium broadly speaking in this one state, which is just an amazing asset to have. So obviously the volume of material that is here, in terms of uranium, would make it an ideal place to have an enrichment plant. Remembering my earlier comment that if we do have the enrichment process step here for a lot of that uranium then you can retain the 90 per cent of the material, that today's reactors don't use, for future reactors. And so that is the first point. Obviously the locality close to uranium production would lend itself to better economics in terms of shipping as well. We only ship 10 per cent instead of 100 per cent of all that material. And the second point is, well it's an Australian technology, it was born and invented here. And I for one, think Australia being very innovative for the resources we have, we haven't really been good custodians of our technology over the years.

A lot of our technologies have gone overseas, admittedly we are a small market for any of these technologies and the engine driver of modern technology is the US economy. So that's why we went to the US with GE Hitachi. But that said, if there was an opportunity to bring this technology back to where it started then that would be a great thing for Australia. It would also mean that we can help protect the technology with the US government, in our own backyard. It also means that more of the economic benefit will come back to South Australia. We have a quite attractive royalty arrangement under the agreement with Global Laser Enrichment. We will be generating between seven and 12 per cent of revenues that GLE produce, coming back to us as royalties. So if a Silex plant is built in Australia, those royalties will come back to Silex shareholders. If a centrifuge plant is built in South Australia, that royalty revenue is lost and that is not insignificant. It is quite a big part of the profit margin from an enrichment operation – would come back as a royalty in our case, or be lost in a case of centrifuge. So a couple of important points on that question there.

COMMISSIONER: Can I just explore whether you have a view about jobs? The potential for jobs in this sort of technology?

MR GOLDSWORTH: Yes. Without getting in to fine details because it depends what sort of plant we would build, whether it's a smaller tails processing plant or a larger enrichment plant, some time in the future, we think there would be for an average sized plant, maybe three million SWU to five million SWU. Separative work units that is, which is about five to 10 per cent of today's market. We think there would be several hundred jobs that would result directly, maybe two to 300 jobs directly and a multiple of that indirectly, in terms of suppliers and services to the plant. That is for a modest size plant. If the enrichment market came back and a bigger plant was built then you could very well see the two, 300 jobs double or triple in the future. But it is an efficient plant, so it's not going to generate thousands of jobs but it will generate hundreds of jobs in our early estimates. But that is all they are at this point.

COMMISSIONER: I presume plant cost is a bit of a finger in the air as well?

MR GOLDSWORTH: No. We have done a lot of work on the plant modelling for both the Warmington – proposed Warmington plant and the proposed Paducah plant. They have quite detailed costing spreadsheets that go forever and down to all the componentry. We have a pretty good handle on the laser systems and we have a pretty reasonable handle on the separator systems and all the other parts of the plant, as you saw in the block diagrams, pretty well known and established in cost anyway. Again, we don't advertise what our costs will be in the future, especially when it is so speculative but – and competitive but we estimate that our costs will be half the cost, or probably less than half the cost of an equivalent sized centrifuge plant in terms of capex. We think we might have an advantage in opex as well, not to that extent but a modest advantage in opex. So I'm still having a discussion with Greg Ward on how much information we can provide on specific costs that we've developed in our models but at this point, publicly, that's all we're saying.

COMMISSIONER: That's fine. Clearly, we're interested in understanding the technology and we'll need to put a cost to it because we have to base our recommendations upon financial analysis as well as cost and safety and risk. So I'm happy that you'll work with Greg and help us as you go along the way.

DR GOLDSWORTHY: Thanks.

COMMISSIONER: The technology also can be used in other areas. Does that provide us an opportunity in this state as well? Perhaps you could just expand on what the technology is also being used for.

DR GOLDSWORTHY: The first comment is that the technology we're using for uranium enrichment is quite specific to uranium. The technology that we have used to investigate enrichment of other molecules is fundamentally quite different. The basic reason is uranium is a very heavy atom. It has very different properties to these lighter elements that we've also looked at over the years. We've looked at enrichment of molybdenum, silicon, oxygen, carbon in actual lab work and then we've done paper studies of other isotopes as well. We've enriched some of these elements in the past. So there's the clear distinction that the technology that we use for uranium is quite different to the laser enrichment technology that we've used for the lighter elements.

Having said that, we've looked at the markets for these lighter elements and we've done some work on molybdenum. Molybdenum was used for production of technetium-99 which is the most widely used medical isotope today by a long way. That market is growing quite significantly as nuclear medicine becomes more broadly used around the world. So we have started looking again at the possibility of a molybdenum production facility. So technetium-99 has traditionally been produced by molybdenum-99 which is extracted from spent nuclear fuel out of a nuclear power reactor.

There's a move more recently to go away from that method of production because particularly the US government is concerned about, well, if you're going to start extracting things from spent fuel then it raises the proliferation question because inside that spent fuel is also some plutonium. So the US government is leading an effort around the world to move away from spent fuel production of molybdenum-99 to either target irradiated molybdenum-99 production or accelerator produced molybdenum-99. Target irradiation involves putting a lug of molybdenum inside a reactor. The neutron is absorbed inside the molybdenum-98 isotope and becomes molybdenum-99.

The problem is molybdenum-98 is only about 24 per cent of natural molybdenum. It's about a quarter of natural molybdenum. So if we enriched molybdenum-98 up towards 90 and 100 per cent you'll get a four times yield from that process. So efficiency is straightaway up four times and cost, hopefully, down four times. The alternative is to irradiate molybdenum-100 which is about 10 per cent of natural in a cyclotron, an accelerator, proton absorption, and that will then decay to molybdenum-99. So the targets for that are also inefficient. Only 10 per cent of the target would go through that process. If we enriched the molybdenum-100 to between 90 and 100 per cent then that process would be improved 10-fold, roughly speaking. So the efficiency and the economics would improve, hopefully, by the same measure.

So there is some work we are looking at with molybdenum. The market is still growing. It's not as big as the uranium market, of course. It's maybe $200 million a year at a guess but I'd have to check on that number. Again, it's very hard to find out exactly what the size of these markets are. Maybe you've been having more success than us but we think it's a few hundred million dollars, growing at the moment. That starts to get interesting in terms of the benefit that you could bring to technetium production and molybdenum-99 production.

We've also looked at silicon enrichment. Silicon comes in three varieties – 28, 29 and 30. The physics says or it has been demonstrated that if you have an isotopically pure silicon material it conducts heat better. Silicon chips, the biggest problem has always been the heat build-up. So the hotter a silicon computer chip gets, the less efficient it performs. If you can get the heat out better and more effectively, that chip will run faster and more efficiently. So they have to use little fans and all sorts of things to try and get the heat away. You can hear it in your computer and your laptop. They try and get the heat out as far as they can. Isotopically pure silicon chips would draw the heat out more efficiently to an extractor.

So we did some work with Simonton Mitsubishi in the late 90s, early 2000s and we produced some chips with a chip maker, or they produced, using isotopically enriched silicon and the benefit was measured. It was, I think, about 5 per cent improvement in speed over extended test periods but they said they needed 10 per cent improvement. So chips have become more compounded with more transistors since those times. The circuitry is now even finer. The heat issues become even more an issue. So we'll probably revisit that at some point. That could be a big industry but the performance enhancement is more marginal. We're talking 5 to 10 per cent. Whether that's enough to interest the chip-makers and whether the cost to benefit works out is another issue. With the small medical isotope markets – carbon, oxygen and few others – they're quite small and they're oversupplied at the moment but we'll probably look at molybdenum and silicon as we continue.

MR HANDSHIN: Would the use of the technology for those purposes require separate facilities?

DR GOLDSWORTHY: Yes, definitely. There would be a clear demarcation between the two technologies and the two facilities in terms of the nonproliferation aspects as well.

MR HANDSHIN: The only other two questions that I had, Dr Goldsworthy, the first of which related to modularity, was whether the (indistinct) capacity of a SILEX facility could be increased, later down the track for example, so after your initial construction phase.

DR GOLDSWORTHY: So our technology is modular. The ideal module is – we haven't really disclosed what we believe is the ideal sized module but it's probably a couple of hundred thousand separative work units plus or minus. Most enrichment plants are millions of units. So you do have that modular expansion capability in terms of those increments. Without going into detail, yes, it's modular. You can keep building capacity as you need to, as your customers want more.

MR HANDSHIN: Given the sensitivity of the technology, could you give us any idea of what, at a very practical level, would be required to actually establish a plant in South Australia?

DR GOLDSWORTHY: In terms of regulatory - - -

MR HANDSHIN: Yes, international agreements, if any, that would be needed.

DR GOLDSWORTHY: We already have an agreement with the United States, a bilateral agreement, specifically for our technology. It took two years to draft. It was signed in 2000 or late 99 maybe and it came into force in 2000. That allows for the cooperation between ourselves and our US counterparts from the government level right down to the shop level in the factory, exchanging information and collaborating to commercialise our technology.

Now, at the moment I think the US government is keen to see the technology stay in America but I'm quite sure that if South Australia decided or made its intention known to try and process uranium more in this country then a conversation with the US authorities would probably need to be had around how we handle that. There would have to be probably extra regulatory arrangements made but I think there is a great need for a higher level of regulatory infrastructure in Australia before we would be able to take on commercial nuclear fuel processing steps, including enrichment and particularly with enrichment being as sensitive as it is.

So I think we're a long way from having the regulatory infrastructure in place. That will take some years. We need to borrow and collaborate with our colleagues overseas, particularly the UK and the US, obviously close allies of ours and close trading nations. Ultimately, there's nothing in principle that would stop us doing that if we really wanted to. We'd just have to put the time and effort in to build a regulatory framework. In terms of other treaties, I think it's just down to the US and Australia with this one. We have looked at other treaties that might affect it. There's the nuclear nonproliferation treaty with the IAEA which would have to be also brought to the party. There would have to be a new level of relationship set up with the IAEA. Then there's perhaps some other bilateral treaties that might come into play with maybe other collaborators or supporters or vendors of various things. Essentially, the main relationship that exists with our technology is with the US government.

COMMISSIONER: Dr Goldsworthy, thank you very much for your evidence. We very much appreciate your coming across to provide with the information.

DR GOLDSWORTHY: thank you very much.

COMMISSIONER: We'll now adjourn until 1500 when Dr Patrick Upson, formerly from Urenco, will give evidence.

ADJOURNED **[12.52 PM]**

RESUMED **[3.00 PM]**

COMMISSIONER: We reconvene at 1500 and I welcome Dr Patrick Upson. Dr Upson, thank you for joining us.

MR HANDSHIN: The Urenco Group is a nuclear fuel company operating uranium enrichment plants in Germany, The Netherlands, the United States and the United Kingdom. It was established in 1970 once the Treaty of Almelo signed by the German, Dutch and United Kingdom governments entered into force. A separate treaty, the Treaty of Washington, was subsequently executed between those governments to allow for the establishment of Urenco enrichment plants in the United States. Dr Upson was a senior executive in the International nuclear industry for many years up to 2010, serving in the Urenco Group for 25 years. He led the project to licence the technology for Urenco in the United States. He is now an independent nuclear consultant.

COMMISSIONER: Dr Upson, we've heard a lot about the theory of the front end of the nuclear fuel cycle. We're particularly interested in this Commission about whether there are commercial opportunities. So it would be very useful for us if you could give us a quick walk-through the sorts of issues that you think about when you're thinking about conversion and enrichment and fuel fabrication.

DR UPSON: You understand the technologies, obviously.

COMMISSIONER: We do.

DR UPSON: For conversion you've got to take the uranium oxide and treat in a kiln with hydrofluoric acid and then fluorine to get the uranium hexafluoride. From a theoretical point of view you need to use uranium hexafluoride if you're going to use either the old diffusion process or a centrifuge process because fluorine only has one isotope. So you really are then just trying to separate the two uranium isotopes, 235 and 238. You're working on the slight difference in weight between the two isotopes. So you have to have a conversion plant which I would wish to site near to the mine so you're not having to transfer the oxide and the ore large distances. That requires a feed of fluorine. I think what has been done in Europe and America is to have the fluorine production near to the conversion plant.

So if I were building such a process I'd be looking at somewhere near the uranium mine and (indistinct) build a fluorine plant and the conversion plant. That's fairly standard technology. It has been around for as long as I can remember. I started in 1973 and the fluorine plant on the site at British Nuclear Fuels (indistinct) was getting to be old by that stage and we were looking into the new one. So the technology is well understood.

An enrichment plant is something a little bit more special. The technology is well known. It started with the gas diffusion process where you take the uranium hexafluoride and you pump it through various porous barriers. It's very expensive, takes a huge amount of energy, probably about a hundred times the amount of energy per unit output that a centrifuge plant takes.

Nobody is now using it. All diffusion plants have shut down and the original diffusion plants were built for the nuclear weapons program and then only later this was converted to making low enriched material for the fuel cycle. Nobody would ever plan to build a diffusion plant. It would have to be built. It's very, very large, very expensive and could not compete in the world market for uranium enrichment.

I know you've heard from the SILEX people today or yesterday. I did a lot of work on laser enrichment in the 1980s and 1990s with Urenco. We came to the conclusion that, although it would work, it would be very difficult to scale up to thousands of tonnes a year. Had we not had the centrifuge process at the time, which was seen as very effective, very efficient and cost effective, we might have continued but we stopped and everybody else in Europe and America, apart from those now connected, GE with SILEX, stopped work on laser. So in my view your only uranium enrichment process that's credible from an economic and industrial point of view in the near future and maybe even in the far future would be a centrifuge enrichment plant.

Now, the centrifuge technology is classified because it can be used for non-civil purposes. So if you wanted to build the centrifuge enrichment plant you would have to either develop your own centrifuge technology, which I wouldn’t recommend – that would take you many years – or do some sort of deal with the technology provider. There really are only two potentials. That's Russia or the Urenco Group under ETC, Enrichment Technology Company.

I would be looking to build a centrifuge enrichment plant close to the conversion plant so that you could optimise your use of materials. I think I've got in my note that fuel production and fuel purchasing from the reactor operators is a seasonal thing. It sounds crazy but it's true. People want to refuel their reactors in the summer when the demand is lower so they're not losing quite so much money in power supply. So people want to have their fuel made in the spring which means they want to have their uranium enrichment delivered around about the turn of the year. Enrichment plants, which have to work 24-7, really need to be operating in advance of some of the contracts and some of the demand. So you need to be running ahead of the orders and building up stock.

Now, the same applies obviously to the conversion plant and the fuel fabricators. So if you were running a conversion plant and an enrichment plant together on one site you can minimise the amount of additional material and the movement of material. I think that would be a far more economic way of proceeding. As I also put in my note, you would have to persuade the fuel purchasers that they want to buy enriched uranium. What they like to do is optimise each stage so that they can get a better price for the stages.

If I were starting at a new site I'd be looking to go right from mining through to uranium enrichment and that would require you to build an enrichment plant near the converter. With high-speed gas centrifuges you can't make them somewhere and ship them to the plant. They're very delicate instruments and if you try to transport them they wouldn’t be in a state to work when you get them to the plant. So you can make the components, as Urenco do and as the Russian industry does. You can make the components at your existing manufacturing site, ship the sets of components out. Usually you would do that in several different sets so that if anybody were to access one of your shipments they wouldn’t have a complete set of components to work from. You would have to then have an assembly facility at your enrichment site where the final assembly was carried out.

I mean, I used to think of it as a little bit like the NASA rocket production. You build your NASA space rocket in the construction facility and then you trundle it along to the site where you're going to launch it at very slow speed and very carefully. With centrifuges you build your centrifuges in the enrichment assembly facility and take them on very slowly around on a specially prepared path in to the enrichment plant and install them. So that that gives you firstly the best chance of your machines working when you try and start them up, it also gives you a lot more security because your final assembly is there on the site, where your enrichment plant is going to be and you can be covered by the same security arrangements. You are not shipping complete centrifuges, where somebody – if somebody was to divert one of the shipments and reverse engineer you could find out how exactly to make and assemble a centrifuge. So from a non-proliferation point of view, I am sure Mr von Hippel this morning, or when you spoke to him, was talking about those aspects. I think building an enrichment plant on the site, so that you can have one complete set of security would be the way forward. Now in the last 10 years, I did a lot of work with the World Nuclear Association where we looked at security of supply and we looked at the longer-term need for fuel – regional fuel cycle centres, where we recommended that one should go ahead with a regional fuel cycle centre. We did exactly what I’ve just described. Went from the mine right through to enriched uranium and was then supplying that region.

I mean one of the reasons that we went ahead in Urenco and built the plant in New Mexico, North America was that the Americans felt that the supply of enriched uranium was too strategic to rely on it being shipped in from the over the Atlantic; were very keen to have a regional centre in America, supplying the American reactors. Now I think there is room for a regional fuel cycle centre somewhere in the Pacific Rim supplying the requirements in the Pacific area because you have got a big demand in South Korea, you have got the demand in Japan. A lot of other countries now, Vietnam, Indonesia, Philippines are talking about the potential for nuclear power and I think there is room for a regional fuel cycle centre. As an enrichment technology man, knowing all the issues about transfer of the technology in to a new plant, I would think Australia is one of the few areas where it would be relatively simple to come up with an intergovernmental agreement to transfer the technology and keep it protected from a safeguard point of view. There are other countries in the Pacific Rim area which it would be more difficult to transfer that technology and get an intergovernmental agreement.

So that is really my thoughts. I've rambled a little bit there but that's really my thoughts on the requirements for building a mining to enrichment plant. I would be very – a bit more cautious about the fuel fabrication facility because fuel fabricators tend to own the design of the fuel. So unless you had a regional need for one type of fuel only, let's say Westinghouse were the only reactor supplier in your region, then fuel fabrication you would have to buy the licence to build all sorts of different designs of fuel. A) that would be expensive; b) you would have to have additional technology in your fuel fabrication plant, so that you could make – manufacture the different types of fuel. So I would be recommending going as far as the enriched uranium but perhaps relying on being able to deliver that to a large number of different fuel fabricators.

COMMISSIONER: Dr Upson, thank you very much for that. Can I just take you to the current market position?

DR UPSON: Yes.

COMMISSIONER: And get an assessment from you about the likelihood of such a facility being competitive in this particular market we are in now and perhaps where you see the market going in the future?

DR UPSON: Yes. the market now is probably not relevant because it would take you 10 years, I would say to get to the point where you had such a regional fuel cycle centre. It could take longer depending on the intergovernmental agreements that you need to put in place. So I think you are in – you need to be thinking about and looking at what is the market going to be in 10 years time. Well, there are 60 reactors currently under construction worldwide. I mean a lot of those are in China but if you had a regional fuel cycle centre in Australia, I think the Chinese market might open up to that centre. China are trying to build their own front end facilities but really it will take a long, long time to catch up with the demand that they are going to have for fuel in China. So I think in the longer term, China will probably become a bit more independent but for in 10 years time, I think it will still be a demand from them.

But if you're looking at other parts of the Pacific Rim area, South Korea are likely to have an increased demand, both from the potential for building new reactors and from making their existing reactors work harder. Upgrading plant ad improving the efficiency of existing plant will require more fuel to make that happen. Japan, I think in August restarted the Sendai 1 reactor. They are talking about restarting Sendai 2 this month and I think by this time next year; you will see a lot more of the Japanese reactors running and it is my personal view that within 10 years time, you may even be getting Japanese ordering new reactors to replace some of the ones that they won't restart. I mean politically that is going to take some time in Japan to establish but they still do not have many other options for power supply in that country. You are getting other Pacific Rim countries talking about the potential for nuclear power, maybe not quite so loudly now as they were before the Fukishima accident. But I see the world demand for nuclear power and for fuel, even to supply the existing reactors, will continue to increase and I think there is room for further plants to be built.

MR HANDSHIN: Thank you. Dr Upson, can I just pick up on a couple of things that you have mentioned and perhaps - - -

DR UPSON: Yes.

MR HANDSHIN: - - - try and explore in a little bit more detail. The first concern is China and you have made reference to a potential opening in the Chinese market, at least in the short to mid-term. Otherwise, does it appear as though the Chinese market will head towards vertical integration?

DR UPSON: Well, that is certainly their plan. I know on the enrichment side, the Chinese purchased the technology from Russia but I understand that the Russian technology they purchased was not even the most up to date Russian technology, so it's not the most efficient enrichment process. I think there is potential if the price is right for the Chinese to – a) with such a huge programme, they would - strategically they would not want to rely too heavily on outside supplies of fuel. But I would see them potentially, if the price for the fuel was right, and I think it could be if you built a reasonably sized fuel cycle centre, in that region, I could see a significant proportion, say up to 25 per cent of the Chinese demand, even in the long term, being supplied from outside of China. Makes sense, firstly for the economics, but also from security of supply. If you have got one national facility and something goes wrong, you have an incident at that facility, you can lose centrifuge capacity, you would really want to have an alternative somewhere, so you are not just relying on the one plant that you have got. So I think there is a potential there that there will be vertical integration in China but I think the potential is there for other suppliers to take a reasonable proportion of that demand.

MR HANDSHIN: Yes. So diversity of supply remains important?

DR UPSON: Sure. I mean, if your reactor is down for a day you're losing $1 million a day, to say nothing about what that's going to do to other industries where you can't supply power. So it's really worth having security of supply. The price of the fuel, the price of enrichment, is not your biggest worry and the strategic issue is one that if - that's why you want to have a regional centre so you're not relying on it being shipped in from all over the world from different suppliers. Also, it gives you that flexibility in the long term. If your plant goes down you've got another alternative.

MR HANDSHIN: Some material that's been received by the Commission suggests that over the coming years there's going to be a substantial decommissioning of existing nuclear power facilities. I'm just wondering how that might reconcile with what you suggested is going to be a continuing increasing trend for the use of nuclear power.

DR UPSON: Well, I mean, take the UK, for example. We retired and we're decommissioning a significant number of the old reactors, but we're now planning to replace them. I think, again, security of supply from an electricity point of view, in the UK we need something for a steady baseload. We're not happy to be relying on gas coming in from other countries, some of which we're not too sure about the security of that supply for the long term, and wind power, solar power, is still not the most economic way forward, and we don’t necessarily have the greatest amount of sunshine here in the UK, and my view, from a UK point of view, is we need to be building more nuclear power to provide a steady baseload, but the government needs to be putting money into research into energy so that these alternatives in 40 years' time are there and economic, otherwise in 40 years' time we'll be standing here saying, "Well, it'd be nice if we had more wind power, but we've got to rely on nuclear again. Let's build some nuclear reactors."

So I think we need to have a balanced supply, nuclear power for the baseload, improving the technology for other longer term demands, as such that we've got a good balanced supply for the next generation, and I think, yes, they're looking at that in many other countries. In America they almost fooled themselves recently with the fracking which has brought in a lot more gas and oil at low prices, but they are now building - they have started building a couple of new reactors on the east coast and in the longer term I think they will come to the same conclusion that fracking is only going to work for a while. We've got to have a baseload, and as their reactors come offline new reactors will be ordered and built.

The one exception is Germany, who for, I think, political reasons, will retire all their nuclear reactors and probably will never build any more, but that's a political decision rather than a sensible energy policy, I think, but I am, yes, very fond of the nuclear industry, so maybe I would think that.

MR HANDSHIN: Just one final question on the topic of market forecasts. Do you see India as having a role in the future demand for enrichment services?

DR UPSON: Sure. There's a big demand in India for nuclear power, but again, like China, I think they will be looking to supply most of their own demand for fuel. I mean, I don't know much about the Indian program, but I understood that they were basing it on a fast breeder reactor and maybe even thorium fuel. So it could be that their demand doesn't have a big impact on what I see as the uranium front-end of the fuel cycle, but I think, like China, in 20 years' time India will be moving forward with a nuclear power program. There will be a demand and once they're building up their own facilities there could be a demand from outside India that in the longer term maybe won't be quite so interesting but would provide a reason for putting new enrichment capacity and new conversion capacity in.

MR HANDSHIN: One matter that you touched on a moment ago was technology, and in particular laser enrichment.

DR UPSON: Yes.

MR HANDSHIN: Do you have any views on whether laser enrichment is likely to become a viable enrichment process in the short to mid term?

DR UPSON: Yes. I've given this view many times in different venues at conferences. We stopped laser enrichment because it just wasn't going to compete with our gas centrifuges when I was with Urenco. We made it work on a small scale, a very small scale, laboratory-type scale. When you come to scaling up it becomes very difficult and you end up with a plant that was very (indistinct) we had a small facility actually based at the UK Atomic Energy Authority in Harwell and that was still working. It becomes (indistinct) with slightly enriched uranium metal flaking out on the inside of some of your facilities.

When we looked at the future cost of decommissioning such a plant, we looked at the costs of scaling it up. For anything that would be a thousand tonnes a year, we came to the conclusion it would never compete economically. Now, there are other issues. The process we were looking at produced enriched uranium metal which is not uranium hexafluoride. So you've then got another completely new process for making new fuel. So now you've got to persuade your safety authorities that the fuel made by a new route is actually going to be as good and safe as the fuel that we've been used to (indistinct) so again, there would be a significant cost of getting that to market.

Now, unless you came along with a laser process which was, say, 50% of the price of uranium enrichment by gas centrifuges, I can't see anybody getting to the point where they're going to develop and use it. Now, Silex may well disagree with me, but we looked at the Silex process. USEC in America worked with Silex for a while and then stopped because they chose instead to try and develop the American centrifuge. GE are working on the Silex process, but their demonstration plant is still some way from having demonstrated the process. Technically it could work, but I don’t see it being introduced in the short, medium, probably even long term. The problem I would also have is I'm a bit nervous about the proliferation issues with a laser process. I think it will be less easy to control the use of the technology.

MR HANDSHIN: We heard some evidence a little while ago from Dr Goldsworthy about some suggested limitations in the centrifuge process, namely, that once they're started they need to operate on a continuous basis and that this leads to underfeeding and therefore stockpiling of uranium inventories and tails assays. Do you see those as limitations with the centrifuge process, and if so, are there any technological developments in the pipeline that might ameliorate those problems?

DR UPSON: They're not a problem, so there aren't any technologies that will ameliorate because there isn't a problem. You're right, and the Silex team are right: you have to operate your machines 24/7. I mean, the problem with a centrifuge is you put it under huge stresses when you run it up to speed. It has to go through several critical speeds and at critical speeds you're in danger of breaking the machine into pieces, of crashing the machine. So you're very careful about how you run it up to speed, but I think you'll find that Urenco and Tenex in Russia have quite a lot of experience doing that and don’t lose machines these days when they're commissioning the plants.

So if you ever come to stop a machine, firstly, you're running the risk next time you try and run it up of machines crashing because you put additional stress on them. Also, when you're running a machine you'll get very small deposits of material on the inside of the machine. I mean, it's spinning like a spin dryer at very, very high speeds. If you stop the machine and even a small piece of the deposit falls out your machine will be unbalanced. So that when you come to start it up it's getting like a spin dryer when you've got a whole load of clothes in and they're not very well balanced, it will start to shake and your machines will crash. So you do not want to strap down your machines.

Now, that's not to say you can't do it. I mean, within the Urenco Group we did that on many occasions but you have to do it very carefully. You lose a lot of output while you're carefully running up and starting the feed again. So you're better off keeping the machines running. Rather than shut them down, I would rather them empty. Just take the feed off and leave them spinning on the vacuum, but that again is expensive. You're taking power and you're not getting any output for it, but it's not a problem. I mean, you do have to judge your manufacturing program or your enrichment programs, such that to deliver – say you're delivering something like 40 or 50 per cent of your demand in November, December every year and the customer may well not have delivered his uranium hexafluoride to be enriched until a few weeks before he's due to have the fuel delivered.

So you're ending up buying material early to enrich early. I mean, the only risk you have there is have I enriched it to the right level? If the customer wanted 4.53 and you guessed he wanted 4.45 you might have to do a bit of blending afterwards, which is an added expense. The way things are working these days is the enrichment requirementss are pretty well known. The enrichment plants are tending to work at standard enrichment levels. If you had a good agreement with a fuel fabricator, again, some of the blending can be done by the fuel fabricator.

So I think working alongside the converters so that you're sharing some of the additional material you need to buy early, working alongside the fuel fabricators so that you are actually producing standard enrichments and the fuel fabricator isn't having to worry about where the enriched level is – you can do some blending at the fuel fabrication, at the conversion to the oxide for fuel. The process can manage the seasonal nature and the 24-7 operation of the centrifuges. If you have a regional fuel cycle centre, that's even better because you can be looking at the whole demand for that region and not just if you were running a small plant with lots of different customers worldwide.

So I don't see it's a problem. I mean, it has been running like that – you've only got to look at the Urenco operations. I have no idea what the figures are but let's say they've got between 25 and 30 per cent of the enrichment demand in the world market. They're running extremely well with plants that run 24-7 and they're profitability is very good. So I can't see that that is giving either a technical or an economic problem.

MR HANDSHIN: Another very closely allied question – and it might be that a lot of what you've just told us stands in answer to this question too. We've heard that centrifuge enrichment facilities are quite energy intensive. Is that a significant factor so far as their economic viability to operate goes?

DR UPSON: You say they use a lot of energy?

MR HANDSHIN: Yes.

DR UPSON: Absolutely not. That's absolutely not the case. A diffusion plants uses a lot of energy. The latest centrifuges – I can't speak for the Russians but I'm sure they're pretty efficient too – almost use no energy once you've got them up to speed. I don't think this is classified but at one point in Urenco at Capenhurst – I'm talking 25, 30 years ago when I was in charge of the plant there – we switched off the centrifuges because there was a strike in the workforce and we weren't allowed to keep the plant running. So we switched off the power and they coasted and when we came back 24 hours later they were still spinning. They don't need a lot of energy once you've got them up and running. So absolutely the energy costs as part of the enrichment costs is very small.

MR HANDSHIN: I think you've probably touched on a number of these matters as well in the course of our initial discussion but I wonder if you might be able to step through and collate for us what you think would be necessary at a practical level to establish an enrichment facility in South Australia.

DR UPSON: Assuming you're not going to start from scratch and try and develop your own centrifuges, because that wouldn't make sense, you would need to approach one of the technology suppliers. Assuming that was Urenco, you would need to establish with the British, Dutch, German and French governments who currently safeguard the technology for use in America and Europe, you would need to approach them and agree an intergovernmental agreement. Now, I've perhaps missed a step. You'd have to get agreement with the technology supplier if they were amenable to some sort of economic deal to supply technology if the governments would approve it, and I'm sure they would be.

The governments' only interest is the safeguard of the technology, such that they would want to be sure that the information and the technology, the different components for a centrifuge, were safeguarded to the same level, the same understanding, as happening in the existing plants in Europe and America. So you would have to develop an intergovernmental agreement which said, "This is how we are going to protect the information in the plant," and that would then have to be ratified in the Australian, the British, Dutch, German, French governments. So it would be an intergovernmental agreement.

Now, when we did the Washington agreement to transfer the technology to America, that took four or five years. When we did the Cardiff agreement, which was for transferring the technology from Urenco for use in France, that took five or six years. So I don't see a period significantly less than that. Maybe one could do it in two or three years but I would be looking at getting a governmental agreement for the transfer of the technology to a new venue. So that would be a real necessity.

You would have to find the site. It may be that the site near the uranium mines is not the best site. Centrifuges don't like being shaken. So you need a fairly low seismic activity level in the site that you choose. I was responsible for Urenco's American plant, getting the licence and choosing the site for the plant, back around about the year 2000. We found lots of good sites but found the seismic activity was just inappropriate. Now, you can cover that by putting in a seismic floor which, if there was seismic activity, would reduce the risk to your plant but I would be looking for a fairly seismically stable location. It may be that that's not right next door to the mine, but during the time you were looking at your intergovernmental agreement you would have to establish the best site for such a facility.

Now, I'm talking here about a seismic event that would cause the plant to crash. That isn't a safety issue. That's an economic issue. If your centrifuge crashes you don't get large amounts of uranium hexafluoride coming out of the plant because the plant is under vacuum. All you get, if a plant crashes you would get air rushing in. I couldn’t guarantee but I'd be pretty sure that you'll get almost nothing coming out of the plant. So you've lost your economic capacity and you had a plant there that you were relying on to deliver to customers but you don’t have a safety risk on the site. That is not one of the big issues.

COMMISSIONER: Dr Upson that leads me in to the question about safety which was - - -

DR UPSON: Yes.

COMMISSIONER: - - - the next on my list. You have had lots of experience, what are the sorts of challenges, safety issues that you have had during your life running these plants?

DR UPSON: Well, centrifuge enrichment plant is very safe. I mean the biggest concern about radiation levels are on your tails storage yard. So the tails which are about a .1, .2 per cent u-235 will be stored. I mean in Urenco at the moment they are just building a tails management facility which is going to take the historic tails from 40 years of operation and turn them in to uranium oxide where they can be more safely stored. But at the moment they are stored as uranium hexafluoride and you will have several thousand tonnes of uranium hexafluoride sitting on your tails facility, tails raft. You have to be concerned about the radiation levels but that’s not a high risk. You just need to make sure that there is some – maybe an earth wall around the facility, maybe a building with some shielding around it and you don’t spend lots of time occupying it but you don’t anyway. It’s a sewerage facility, you have to go in occasionally and monitor and check that the stainless steel containers are in a good condition. Ultimately you would have to build a deconversion plant where you turn the material back in to uranium oxide. The biggest safety risk in the plant would be reuse of uranium hexafluoride.

To be honest, the biggest risk in that is the fluorine. If you had a release of uranium hexafluoride, as soon as it comes in to contact with moisture in the air, you will get hydrochloric acid and uranium oxide dropping out. So any uranium would be fairly local on your plant but you might have a cloud of hydrochloric acid gas which is not something you want to be breathing in. So I mean my view was that provided your requirements for safety covered you for the chemical risk, the atomic nuclear risk was more than covered. Now in the 25 years of working for the Urenco group, we never had in my time a major safety hazard. We had several occasions where we lost some plant capacity because machines crashed and we had a significant time where we were decommissioning some of the old plants which had finished their lifetime service and we cleaned them up. But again, that has a low risk of radiation because you are cleaning small amounts of uranium under the plants. But they are very safe. So the worst that can happen is a machine will crash. If it's a single machine, it just sits there dead in your cascade of machines. If the whole plant were to crash, you will get air rushing in and you've got an economic problem because you can't supply from that cascade but you haven't got any reuse of radioactive material.

We always have some difficulty coming up with a scenario when we were doing safety planning. We always had exercises and the usual scenario was a forklift truck had driven in to the tails yard and pierced one of the tails containers and material had come out. We did even look at a small aircraft crashing on to the tails raft and releasing uranium hexafluoride but actually the safety risk, even of that, was pretty low. So there are small chemical plants - I am not sure I should say this but when I go to the Capenhurst site, the Urenco plant was much safer than the chlorine plant run by ICI about five miles away. And the chemical hazard from the chlorine plant that has releases of material which shut the motorway driving past on at least three occasions that I can remember. We never had incident on the uranium enrichment plant, nor would I expect to have one. Absolutely one of the safest processes in the nuclear business.

COMMISSIONER: Thank you. The final question we have for you, Dr Upson is to get a sense of the number of people and the sorts of skills that might be involved in a regional fuel cycle centre.

DR UPSON: Okay.

COMMISSIONER: Just to give us a broad idea?

DR UPSON: Well, I really can't speak about the conversion plant but I can't – I don't think that requires huge numbers of people. It is just a small chemical plant.

COMMISSIONER: Yes.

DR UPSON: Now you are not talking about hundreds of thousands of tonnes of material going through each year, you are talking about tens of thousands of tonnes of material. So it's a small chemical plant and you would need chemist, engineers - uranium enrichment plant the big demand is when you are building it. You would need to have some skilled people for assembly. What Urenco did in both France and the USA is send a small team of experts, who then trained up the local people for the assembly but that is assembly of some delicate material. It's a bit like aerospace. If you are thinking about somebody who is assembling aerospace jet engines for aircraft, it's the same sort of skills. You need to be able to control and position items very carefully; you need to have a clean room technology. So while you are building the plant, you would need those sorts of skills. Running the plant itself, you need some process operators. Again, it's really like a small chemical plant. But at the Urenco sites the numbers of people running it are pretty small. You would be looking at maybe between 100 and 200 people running the plant. Some process operator skills, some maintenance skills. You don't maintain the centrifuges but you have got various pumps and feed systems around that that need to be maintained.

So I would be looking at a series of mechanical, maybe one or two chemical engineers but it is not something where you need some highly specialised nuclear skills. It is just basic chemical engineering and mechanical engineering. For the plant that Urenco built in New Mexico, again we took some Europeans over for the first part of the operation, to train up the locals but we brought in the locals from around the Hobbs County where the plant is situated and there was people skilled in the oil industry. So again, engineering, mechanical engineering, bit of chemical technology. So those will be the sort of skills. But if – I am sure you would have those skills in the Australian region where you are. It's not a huge number of high technology people with nuclear background. You don't need that. You will need some from the point of view of the safety and the environmental team but it is nothing that you couldn't easily cope with.

COMMISSIONER: And the capital cost of such a facility?

DR UPSON: Yes. Depends what size you are – I couldn't tell you for a conversion plant.

COMMISSIONER: No.

DR UPSON: Although a centrifuge enrichment plant – and I have built many, you would be looking at maybe I think two or three billion Euros. I don't know what that works out in Australian dollars. Say two billion pounds.

COMMISSIONER: Okay. Dr Upson, I thank you very much for very practical advice. We appreciate you spending the time with us.

DR UPSON: That's okay. And if there is anything else I can do to help you with your decisions, you only have to call on me.

COMMISSIONER: Thank you very much.

DR UPSON: Not necessarily at 5.30 am every time but - - -

COMMISSIONER: We promise we won't.

DR UPSON: That's okay. Thanks very much.

COMMISSIONER: Thank you. We will adjourn until Wednesday, the 14 - - -

MR HANDSHIN: Twenty-first.

MATTER ADJOURNED AT 3.50 PM UNTIL WEDNESDAY, 21 OCTOBER 2015