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 USEC 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 and Global Laser 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]