NUCLEAR FUEL CYCLE ROYAL COMMISSION

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SPEAKERS:

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TRANSCRIPT OF PROCEEDINGS

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COMMISSIONER: Good morning. I welcome Thomas Marcille from the US. We are catching up an opportunity we missed a week ago on low carbon energy generation options. Mr Jacobi.

MR JACOBI: Mr Tom Marcille was an industry leader with nearly three decades of service to the industry. He's held senior and principal engineer positions with GE Nuclear, chief engineer at Los Alamos National Lab and chief operating officer and VP of engineering at NuScale Power. He's currently the vice president of reactor technologies of Holtec International, with the ultimate responsibility to develop and licence SMR-160, a passive light water reactor system for the emerging global power market. We call Mr Tom Marcille to the Commission.

COMMISSIONER: Tom, if we can start in the broad and we'll give you the opportunity to go and look to the Holtec reactor in a little while but I'd just like to start with a broad question about where you see small modular reactor development in the US at the moment?

MR MARCILLE: Small modular reactor development in the US is relatively strong. There were a couple of players who have bowed out due to lack of immediate market opportunities within the United States. The players who remain active in the US I believe all see a very, very strong global market and as a result, in my personal view, SMR development in the US is very, very strong. There's different types of small modular reactors, if you will, both of the light water variety and the non-light water variety, and the companies that develop those likely have different horizons or time frames as a function of the cooling technology associated with their design.

COMMISSIONER: Would it be fair to say that you're expecting SMR or the application of them outside the US more than inside?

MR MARCILLE: No question. The United States has huge, huge options with respect to electricity production fuel sources. We burn a great deal of coal. We have huge inventories of natural gas. We have nearly 20 per cent of our power from commercial nuclear power plants. It's arguable that no country on earth needs power less than the United States. There's nearly 75 commercial reactors under construction around the world today. Only four of those are in the US. As a data point, I think that would suggest that the vast market is outside of the United States.

COMMISSIONER: We might move on to more specific questions on Holtec.

MR JACOBI: Can I just pick up where he Commissioner has left off. What particular niche in the market do you think that SMRs may serve as opposed to larger pressurised water reactors?

MR MARCILLE: There's a couple of ways to answer that question. I generally stay away from the term "niche" when characterising the marketplace for SMRs. There are niche opportunities where they fit because of their size. A hundred megawatt electric nuclear power plant can serve somewhere in the neighbourhood of 70 to 85 thousand homes. A very, very large commercial nuclear power plant requires a huge user base in its vicinity. So while there are niche opportunities, some of the advantages of small modular reactors that allow them to compete with large plants are the ability to dispatch electricity in relatively small incremental amounts. It takes that so-called single shaft risk out of play.

When a thousand or 1200-megawatt electric nuclear power plant goes down, an owner operator needs to have 1200 megawatts of electricity in his back pocket to continue to provide the power that's now offline. A number of SMRs takes the susceptibility to that challenge out of play.

MR JACOBI: We haven't seen SMRs develop in the 80s or the 90s or the early 2000s. Is there a view about why SMRs haven't been fully developed and installed until now?

MR MARCILLE: When commercial nuclear power took off wholesale, it took off with oxide-fuelled light water reactors for lots and lots of reasons, whether good or bad. The early light water reactors were in the two and three hundred megawatt electric range. So one could suggest that we started out with SMRs and the so-called economies of scale for these active system light water reactors dictated that we increase the size of the plant to improve the economics of that model. SMRs today - certainly passive light water reactors - are an entirely different animal. So the economies of a small light water reactor and SMR, an integrated passive SMR, are vastly different than a large light water reactor because we're comparing apples to oranges here.

MR JACOBI: Perhaps we can pick that up as we go along because we're interested to understand - the Commission has had the point made to it with respect to economies of scale with larger plants. But perhaps we can turn to the particular Holtec design. We've got a slide I think that picks up and we'll get you to walk through some of the design features. Could we come to perhaps the overall plant design, and I think we've got a slide. Do you have that in front of you, Mr Marcille?

MR MARCILLE: I've got a picture of the overall plant in front of me, yes.

MR JACOBI: I just wonder whether you could explain the overall plant design and the features.

MR MARCILLE: This plant looks similar to other light water reactors in that it has a silo-shaped structure which is referred to as the containment enclosure structure. In a conventional large light water reactor we refer to this concrete superstructure as a shield building. That thick heavy concrete shield protects a metal containment inside. The original light water reactors, the containments were actually steel-lined concrete containments and the concrete was fully necessary to facilitate the containment performing its design basis functions.

In this power plant that concrete steel structure or that containment enclosure structure does not form part of the containment. The containment is a freestanding steel structure inside there. So this structure not only protects the containment but it facilitates passive heat rejection of all of the decay heat from the reactor fuel and the spent fuel which is stored inside the containment.

There's a couple of other buildings there. On the left there's a complex referred to as a turbine island with a standard ranking cycle turbine generator and a condenser. There's an auxiliary building, most of which is below grade, which contains the solid, liquid and gaseous radioactive waste-handling systems as well as most of the H-back and mechanical and electrical systems to service the plant.

On the right there's a structure called the fuel handling building which is a structure that allows us to take receipt of new fuel and also incorporates the equipment which allows us from the day the plant operates to have the interim spent fuel storage capability integrated within the plant design. So It's really those four areas: the nuclear island, the turbine island, the fuel handling building and the auxiliary building.

MR JACOBI: If we can come to the containment structure, in terms of its design, does that meet the design requirements in both the United States and Europe for an aircraft impact?

MR MARCILLE: Yes, absolutely. It's an extraordinarily robust structure that uses a technique called SC wall construction. So it's rings of heavy steel within which a six-foot thick layer of concrete is poured. It makes it extraordinary strong and resilient. It's very, very similar to the large interim SC wall casks that Holtec manufactures for the storage of interim fuel these days. Those devices are tested by firing missiles that replicate the impact force of say an engine from a commercial airliner.

MR JACOBI: Perhaps if we can come to the next slide that shows the internal layout and shows the layout below grade.

MR MARCILLE: Okay.

MR JACOBI: Could you explain the basic features that are below grade in that design.

MR MARCILLE: As I talked about before, the auxiliary building, the vast majority of the physical structure and the equipment is below grade. We'll see in a slide coming up here that fully half of the containment itself is below grade. So all of the good stuff, all of the nuclear material, is located below ground level. In the case of the auxiliary building, having the liquid and solid and gas waste systems below there is an economically smart thing to do because that's where those materials are essentially produced. The reactor is below grade. So by locating that supporting equipment at the same relative elevation below grade we eliminate the need to pump up all of those solids and liquids.

There's another slide that I think is going to come up here that shows the containment with the reactor and steam generator inside. It's slide 4 in the deck that I have.

MR JACOBI: Before we get there, can I just ask about the overall plant footprint relative to perhaps a Westinghouse plant site.

MR MARCILLE: This is extraordinarily compact. Large light water plants like a Westinghouse site, for example, were not originally laid out to make the site simple to secure, for example, and because of the size of the physical structures and the ancillary equipment it required a very, very substantial site plan. This plant here, the structures that we've looked at - the turbine island, the auxiliary building, the fuel handling building and the nuclear island - all fits within an area of approximately five acres or slightly less. That's equivalent to about a football pitch.

MR JACOBI: Perhaps if we can move on to the containment structure, which is slide 4. The Commission is particularly interested in understanding aspects of the containment structure that are relevant to its safety and its design features. I just wonder whether you could walk us through the key features and systems in the containment structure and their relevance to safety.

MR MARCILLE: One of the things to understand about a nuclear power plant is all systems are classified in terms of their significance to safety. They are either safety systems or non-safety systems. Safety systems are those which are required to function in order to keep the fuel always covered and cool such that there's no release of radioactive fission products to the environment. Unique to this design for light water reactors is that 100 per cent of the safety systems are located inside the containment. There is no other light water reactor in the world or on the books, whether large light or SMR, that has all of the engineered safety systems within the containment. Having them inside the containment is important because the containment is designed to maintain a pressure seal so no penetrations in the containment then need to be maintained and maintained in an assured condition outside of the containment to ensure that a safety system will be available. So that's an important characteristic here.

All of the safety systems in this power plant - every single one of them - has the ability to operate in the complete absence of electric power. So the safety systems, those which ensure that coolant is circulated at all times to keep the core covered and to cool the fuel in the reactor and the spent fuel pool rely on no electric driven pumps or circulatory modes. It's pure convection and natural circulation. That's a unique and important feature of this design.

MR JACOBI: If we could come to the components themselves within the containment structure, I'm just wondering perhaps whether you can give the Commission a quick walk-through in terms of those components and perhaps with a particular focus upon the method for heat dissipation.

MR MARCILLE: It's a little difficult to see in this particular view because of its complexity but the reactor is an orange-coloured vessel in the lower 25 per cent of the containment. That reactor is connected via an integrated duct to a large steam generator. The heat produced by the core causes a temperature gradient from the bottom of the reactor core to the top of the reactor core which allows the coolant to rise due to a density difference. That coolant when it rises up the middle of a tall chimney through a steam generator wherein it turns around and falls down through the tubes of a steam generator so this natural mode of force driven by natural circulation and temperature and gradient difference allows the natural circulation flow path.

The steam generator of course is the means by which the heat is removed from the reactor and either sent to a turbine or a condenser or the atmosphere of the ultimate heat sink. There's a large series of what are called heat dissipator ducts. It's up in the top of the containment and it looks like a series of purple parallel pipes. That again is a natural circulation heat exchanger. It's essentially a radiator. In the case that there's an accident or an upset, the decay heat from the fuel causes water in a small isolation condenser to boil, the steam is routed to the heat dissipator ducts where it condenses on the cold containment wall and sets up again another natural circulation loop.

So the entire concept of this plant is to make sure that in normal steady-state operation natural circulation facilitates removal of heat from the core by way of the steam generator. If there's an accident or an upset in the steam generator and it's no longer available or able to function, the heat dissipator ducts take that decay heat and transfer it to the atmosphere again via natural circulation. In the case of a break of a duct or a pipe or opening of a pressure release valve, steam is released from the reactor coolant system whereby it condenses on the shell of the containment and is transferred to the atmosphere via the same natural circulation modes.

MR JACOBI: Could you give some indication of the dimensions of the containment.

MR MARCILLE: The containment is precisely 45 feet in diameter and it's roughly 180 feet tall. When I say "roughly", the exact shape of the top of the containment is still under development and there's a large pour on the top of the reactor. But 180 feet tall and 45 feet in diameter gives you a good sense of that. About half of that containment is above grade and half of that containment is below grade.

MR JACOBI: 45 feet in comparison to the diameter of a containment in a large reactor, in terms of relativities?

MR MARCILLE: So a large conventional light water reactor, pressurised water reactor, a steel containment vessel is approximately 200 feet in diameter and 200 to 220 feet tall, all above grade. In this particular design, the containment enclosure structure itself, that steel concrete super structure that surrounds the containment is (indistinct) in diameter and the top of that structure is approximately 120 feet above grade.

MR JACOBI: Perhaps if we can come to deal with the reactor pressure vessel and the coolant system? And I think we have got a slide first that deals with the coolant system and then to the pressure vessel. We're just interested to understand again, the particular design or safety features related to the way that that particular coolant system operates?

MR MARCILLE: So if you look at this slide titled reactor coolant system, we start out with an exhibit of what is seen by many people as a traditional integrated pressurised water reactor concept whereby the steam generators are located physically within the reactor vessel. It's a clever idea but from a practical operation standpoint it introduces huge challenges and problems. The reason people integrate the steam generator and pressurizer inside of a single reactor vessel is to eliminate large pipes and eliminate the propensity for a so-called large break loss of coolant accident or a LOCA. What Holtec – we're a company who manufactures heat exchangers and steam generators for a living and we understand some of the challenges associated with dependable operability of steam generators and fabricability and inspection requirements. Having steam generators integrated inside a reactor vessel makes it extraordinarily difficult to disassemble the reactor vessel to service or inspect the internals.

By having a concept where we connect the steam generator and the reactor vessel together in the SMR-160 by having a welded duct, we have completely eliminated pipes and the susceptibility associated with pipe breaks or leaks and we've used a more traditional steam generator concept that's reliable and readily operable and inspectable. Additionally, we do not need to disassemble the steam generator or remove the steam generator from inside the reactor to service the reactor and refuel it. So by having the offset design we're easily able to access the core and internals of the reactor without the cost and challenges of disassembling the entire system and the steam generator.

MR JACOBI: Does that have an effect overall in reducing the time of – time taken to load or unload fuel?

MR MARCILLE: Absolutely. Absolutely. Furthermore, by ensuring that all of the safety significant components of the reactor coolant system significantly the welds, all of the critical welds on the pressure boundary of the reactor vessel itself for example, we are able, or an owner would be able to easily inspect those welds as is required by the ASME code. Some SMR vendors have developed solutions much like the concept in the upper left hand corner whereby the pressurizer and steam generator is all inside of the reactor vessel and it makes it difficult, if not even impossible to inspect those welds. As a result people are working to develop a new risk informed inspection criteria for the ASME code. It's an interesting idea, but it doesn't exist currently. So it introduces some risk for those concepts.

MR JACOBI: I'm interested to understand the extent to which passivity is a feature of this particular design?

MR MARCILLE: Passivity is a huge aspect of this design. The steam generator, the difference in height from the bottom of the core to the top of the steam generator is approximately 120 feet, so there is an extraordinarily large chimney which creates a very, very large thermal siphon effect. That thermal siphon effect gives us a very, very fast high velocity mass circulatory effect which not only facilitates good heat transfer because of the flow rate but it also creates turbulent flow in the core for stable thermal hydraulics and heat transfer. So while the steam generators are very, very large in this design, it's designed that way to affect a very, very turbulent high mass flux of the natural circulating coolant.

MR JACOBI: Another aspect I want to pick up is the extent to which there is a – this uses established design concepts? And I'm just interested to understand the extent to which this uses concepts that are understood, or it seeks to develop or innovate upon those concepts?

MR MARCILLE: Yes. Our – what we like to say is we're practically innovative. We, as a company, we design and manufacture complex nuclear equipment for a living. And it's in our best interest to use dependably available materials and rely on well-known and tested important heat transfer and pressure phenomena. So what we have done is taken reliable and well-known physics and phenomena and we've integrated them in some innovative ways to be able to eliminate the type of equipment which has historically been that which might fail and cause challenge to the safety of large light water reactors. There's no unobtainium in this reactor, in this concept.

MR JACOBI: Can we come to the reactor pressure vessel itself? I am just wondering about whether you might explain again, the key concepts of that by reference to the slide and in particular explain some of the acronyms I think that are used on the slide and we will come to some specific issues in a minute.

MR MARCILLE: So I'm not precisely sure of your question. I'm looking at a slide right here called reactor pressure vessel - - -

MR JACOBI: Yes.

MR MARCILLE: - - - features.

MR JACOBI: That's right. Yes.

MR MARCILLE: So if you look at – if you look at this reactor pressure vessel, it uses a commonly used carbon steel material, Clad Wood stainless steel and designed to section 3 of the ASME code. It has no penetrations, no holes in the reactor vessel at any location substantially close to the top of the core. That is important because penetrations can fail and leak. A boiling water reactor vessel, as an example, the control blades of a boiling water reactor enter from beneath the vessel, so the bottom head of a boiling water reactor has many, many large penetrations drilled in to it. And as a result, every one of those penetrations requires a leak type weld and seal and must be regularly inspected. And those seals can fail and leak and so that introduces the possibility of accidents. By eliminating those penetrations and locating penetrations at elevations high above the core, we greatly increase the likelihood that the core never becomes uncovered within an accident. The core uses traditional light water reactor fuel bundles and traditional light water reactor control rod drive mechanisms and control blades which are mounted – the control rod drive mechanisms are mounted on the top of the reactor, much like a traditional PWR. This design uses a cruse form control blade much like a BWR because the system contains no boron. Boron is in essentially all pressurised water reactors in operation and it's an extraordinarily corrosive material, leads to very, very many complex problems and challenges with respect to water chemistry and crud and corrosion and requires significant systems to filter and clean up the water. By eliminating the boron, we have a much, much simpler water chemistry for a cleaner, more reliable system. We eliminate some of the major drivers that lead to stress corrosion cracking in reactor components. By using an interesting concept, the cruse form control blades we're able to compensate for the lack of boron in the system to ensure that we have a reactor that can always be shut down and safely controlled. The water being heated up in the reactor as a result of a Delta T across the core, rises and exits from this large nozzle, it's approximately 40 inches in diameter and it exits the reactor pressure vessel out that nozzle within an inner riser pipe. That riser pipe extends up through the steam generator where it exchanges its heat with the secondary coolant and the water returns through that large nozzle, outside the central hot leg where it re-enters the reactor vessel in the downcomer region and then recirculates through the reactor itself.

MR JACOBI: Pick up the question that I asked about the coolant system, to what extent does the reactor pressure vessel use existing known PWR design or engineering features as opposed to using more innovative or untested techniques?

MR MARCILLE: There's really nothing unknown or untested here, it's a natural circulation is – for light water reactors is a concept that's been around for decades. US Navy reactors are PWRs that operate over a range of their power entirely on natural circulation, using the same types of temperatures and pressures and materials. So there's nothing new here in terms of the individual components. It's the geometry and the combination of those components that allow us to take advantage of known technology to come up with a simpler and safer solution.

MR JACOBI: To come to the topic of water use associated with the reactor, in terms of volumes what are the – what are the volumes of water required to be able to cool the system?

MR MARCILLE: Well, the water volume that is within the plant is substantial as a function of the power density of the reactor. For example, the reactor coolant system has approximately four times as much water per megawatt of thermal power than does the Westinghouse AP-1000. And that's because of the large central riser in the stem generator; it's a huge volume of water. This plant is designed however to be air cooled which means that the waste heat from the steam cycle that drives the turbine can be dissipated to the atmosphere using natural circulation air cooled condensers. Holtec as a company has a heat transfer division which has designed and manufactures and sells around the world large frame air-cooled condensers, so we've optimised the plant to rely on no external water sources to dissipate the waste heat.

MR JACOBI: Again, to pick up the air cooling aspects, you refer to it, are the air cooling systems that Holtec manufactures, manufacturing for other energy systems? For other types of plants?

MR MARCILLE: Yes. Air-cooled condensers are significant as compared to say wet condensers, either natural, draft or for circulation. Large cooling towers, a lot of people are familiar with seeing those, which are used for nuclear power plants, gas plants, coal plants. Because of concerns about water worldwide, more and more power plants are going to air cooled condensers. Some plants are replacing their wet draft cooling towers with air-cooled condensers. Certain parts of the world for example, in the Middle East, which have very, very little access to water, simply don't have wet cooling as an option. So a plant that is designed and optimised to reject its waste heat exclusively via air-cooled condenser is mandatory in our estimation to be able to capitalise on the market.

MR JACOBI: Do you – we have heard a bit about the concept that where one seeks to air cool a nuclear plant there is some compromise in terms of the efficiency or energy output of the system. I am just wondering about the extent to which there's a compromise if one does air-cool the plant?

MR MARCILLE: Yes, there is. In fact there's about a two to three per cent thermal efficiency penalty. So for example, a plant that's able to convert 33 per cent of its thermal energy to electricity might only be able to convert 30 to 31 per cent of its thermal energy to electricity using an air cooled versus a wet cooled condenser. Air cooled condensers also take up a substantially larger footprint than do wet condensers and air cooled condensers are substantially more expensive relative to wet condensers because of the vast volume of metal and labour to manufacture those large air cooled condensers. Air-cooled condensers require a large surface area to dissipate the heat, relative to a wet condenser.

MR JACOBI: Yes. The particular plant has a power rating, as I understand it, of 160 megawatts electric, is that with the air-cooled system or is that with wet cooling?

MR MARCILLE: That's with the air-cooled system.

MR JACOBI: Can I just come back to the volume of water that's used within the plant itself? I'm right in understanding that that particular water does not need to be replaced?

MR MARCILLE: That's correct.

MR JACOBI: And you express it in terms of a comparison to the volume of the Westinghouse, I am just interested in knowing what's the absolute number in terms of the amount of water that's required within the system?

MR MARCILLE: I don't have that number off the top of my head but I could provide that to you separately.

MR JACOBI: Thank you. I'm just wondering perhaps if we could turn to the question of licensing. I think we have got a slide that might pick that up. I'm just interested to understand the licensing approach that Holtec proposes to go through with respect to the SMR-160?

MR MARCILLE: Sure. Let me just explain that as an American company, designing commercial nuclear technology in the United States there's a natural inclination, even expectation, that we would licence the plant in the United States. While that's fundamentally not a requirement to deploy the power plant around the world, in other words, it's possible for a national regulator outside the United States to first licence the SMR-160. Having said that, there are two standard methods to licence commercial nuclear power plants in the United States. There's a two-part process known as part 50, under which every single operating nuclear power plant in the United States was and still is licensed. In that particular licensing paradigm, a preliminary safety analysis report is submitted to the regulator for review and if the regulator believes that the plant, as specified in the preliminary design is safe, will grant a construction permit to an applicant. Subsequently the applicant should apply for an operating licence to be able to turn the keys on and run the power plant.

The other process is known as part 52 or design certification. And the United States and the NRC, some 30 years ago, started to develop this concept. Part 52 requires that a design be complete in the estimation of the regulator in order to certify that that design is standard and subsequently that design cannot easily be changed. So an applicant must build that standard certified plant. Holtec believes that the part 52 design certification process is not amenable to SMRs. Part 52 design certification process in the United States applies to enth of a kind large light water pressurised water reactors and BWRs not to small reactors. Further more, the nuclear regulatory commission in the United States has admittedly lost much of the experience associated with the part 50 process that was applied and as they matriculated the part 52 process they didn't keep the regulations associated with part 50 up to speed if you will.

So Holtec finds the part 52 process to be far too arduous in terms of time and cost and risk. The AP-1000 experienced 19 revisions to its design certification and required some 15 years and arguably close to two billion dollars to design and develop to the point it was ready to be certified and brought to the market. That's a huge, huge commercial obstacle for almost all developers and sensible people would question whether anyone will ever try to design and certify again in this country.

I will go so far as to say that reactors that are licensed and operated around the world are licensed via processes that are much more in stride with the NRC Part 50 process and the Part 52 design certification process. Design certification under a Part 52 is a licensing concept that is unique to the United States. So if the market is global outside the United States and all reactors in the world are essentially deployed under the Part 50 or Part 50-like protocol, it seems to make sense to us to pursue that path.

MR JACOBI: We've heard a little about the IAEA's generic reactor safety review scheme. Is that a process that you propose to pursue or - - -

MR MARCILLE: The IAEA generic safety review process is an option that is available to allow an IAE member state to sponsor a design for review by the IAEA to ascertain its licence ability. So a foreign government could, for example, choose to approach the IAEA if they're a member state and say, "We want you to go through this process to review this and tell us what you think. We want to ascertain the licence ability in order to consider moving forward with a commercial project and we are very, very interested and receptive to that concept and have had significant conversations with interested stakeholders around the world. That's a process that's been exercised repeatedly by a number of international reactor developers over the years.

MR JACOBI: Picking up from there in terms of I think the slide shows a logic and approach to a preliminary safety analysis report and I'm just wondering perhaps whether you could walk us through in terms of the approach that Holtec intends to take with respect to that particular analysis.

MR MARCILLE: Rather than get too complicated here, I'll try to explain it simple ways. The process that Holtec is pursuing is to develop a preliminary safety analysis report which is in lock-step with a preliminary design specification. So we develop a design specification, the analysis and system design descriptions and PNIDs that are reflective of the individual systems and the integrated plan. As the design becomes more mature, we spend more time and money doing the detailed analyses. A design specification matures from a concept to a preliminary design to a final detailed design. A safety analysis report matriculates as well from a preliminary safety analysis to a final safety analysis report.

So we have a cojoined licensing documentation development process which ensures that the configuration managed power plant design specification is able to substantiate the safety analysis which is described in the PSAR. The preliminary safety analysis report is a living document. As the plant design matures, the safety analysis report will mature as well until the preliminary safety analysis report is able to mature to final safety analysis status.

MR JACOBI: I think that might lead us into a more general question about where Holtec is at the present time in terms of the overall development of both the concept, the design and the safety case. How far are you away from a point in which you might be in a position to talk about the commercial deployment of the plant?

MR MARCILLE: The work schedule today has the preliminary design of the reactor, coolant system and all the engineered safety systems within the containment and included in the containment and containment enclosure structure complete by the end of calendar 2016. The preliminary design specification will be complete by the end of next year for those systems that we believe are critical to allow a knowledgeable regular to ascertain the safety and licensability of the design. The first iteration of the preliminary safety analysis report will be done at the same time.

Now, the preliminary safety analysis report will itself become richer in terms of broad content as the design continues to matriculate and as we satisfy commitments made in the PSAR. Let me just give you an example. In order to operate a commercial nuclear power plant, for example, certain testing must be done. In a preliminary safety analysis report the US NRC requires you to describe your test program. So you make commitments about the kind of testing you will do to allow a preliminary safety analysis to be codified in the form of a final safety analysis report by obtaining the test data that verifies the operation and performance of the power plant and the codes as simulated.

Again, our concept is to develop a preliminary design specification and a preliminary safety analysis report and to then achieve an opportunity with a commercial client to submit that preliminary safety analysis report under the review of a competent regulator for consideration of granting a construction permit. At such time the design will matriculate through the engineering specifications, the procurement specifications and the construction drawings. It's unlikely that Holtec will continue to develop towards final safety analysis and final design unless a client steps forth.

Our business plan, we're not putting all our eggs in one basket. We're not spending the huge amount of money and effort to develop a standardised Part 52 design certification, that being required to get to the starting line for a Part 52 concept. The Part 50 approach with the preliminary safety analysis report allows us to develop opportunities in the marketplace much sooner and then to continue the investment in the business and the technology if and as the marketplace develops.

MR JACOBI: I just want to understand the scale of the investment required nonetheless to even reach the end point of having a finalised preliminary safety analysis report where you've in fact undertaken the testing.

MR MARCILLE: I would suggest to you that the Part 52 process is so prescriptive and so overly prescriptive that it requires people to do things necessary to satisfy the process that is Part 52. Another way to say it is, I believe that Part 52 is a less efficient use of time and money to get to the market than is Part 50.

MR JACOBI: I'm just interested to understand the extent of Holtec's investments to date and the extent to which it proposes to make further investments to reach the point of having a preliminary position such that it could go to an international regulator to seek final approval.

MR MARCILLE: We have a substantial program here. This design has been under development for approximately five years. We are an efficient organisation; after all, we design and manufacture capital nuclear equipment for the nuclear power industry. We are the largest exporter of capital nuclear equipment in the United States. One would suggest that we know how to do it better and quicker than other people. It's not an experience or a learning path for us.

That being said, in addition to the design activities and investment that's been made here over the last five years, we are currently constructing a 500,000 square foot advance manufacturing facility in Camden, New Jersey, that includes a 25,000 square foot half-pint scale integral test loop and training facility for the SMR-160. So that is a multi-hundred million dollar investment, that factory and test loop. Those facilities again are under construction as we speak.

COMMISSIONER: Thomas, in some of the evidence provided to date the economies of scale of small modular reactors has come up. I wonder if you can help us understand in comparison to larger plants the cost economies and the advantages of small modular reactors.

MR MARCILLE: Let me help by saying that – let me liken a large light-water reactor to a large apple and suggest that a lot of people think of small modular reactors as little apples. I would ask you to think of a small modular reactor like the SMR160 not as a little apple but a little orange. So now I'm comparing a big apple to a little orange and they're entirely different. The apple is sweet, the orange is sour. You get the picture.

In terms of how is it possible that – and given that the industry decided for many years that we needed to make the plants bigger in order to realise economies of scale, a single nuclear power plant with a single reactor requires a certain number of men or women to operate the plant; reactor operators in the control room, for example. Whether the reactor produces 100 megawatts or 1000 megawatts, in the current paradigm it requires exactly the same number of people in the control room. A large three-loop pressurised water reactor has three steam generators and reactor cooling pumps and a pressuriser, all the same equipment in a large plant. That equipment is simply bigger than in the small plant.

Large light-water reactors incorporate redundant active safety systems. Redundant active means multiple systems requiring electricity to actively circulate coolant through the use of pipes and pumps. In the case one of those pieces of rotating equipment fails there are redundant pump systems available to serve that function. The SMR160 uses single trains, diverse trains of passive safety systems. So rather than having two or three or four versions of the same active system, we have a single passive safety system with diverse means to deliver the same passive safety function.

By so doing the SMR160 eliminates huge amounts of active equipment, capital equipment that needs to be purchased, that needs to be installed and, importantly, needs to be operated and maintained. Safety significant equipment has an extraordinarily high burden of maintenance and inspection over the course of its operating life. By eliminating whole systems and components, not only do we eliminate the capital investment up front but we substantially eliminate major, major parts of the operation and maintenance costs for the plant over its entire life cycle. So that's a simple high-level explanation of how a small integral PWR SMR, like the SMR160, can have a production cost of electricity that's less than a large light-water reactor today.

MR JACOBI: Can I just pick up from your high-level discussion. You referred to the elimination of redundant active safety systems. I'm just wondering whether you could identify other features of the design that have involved elimination of components, because this is not something we've necessarily heard with respect to other SMR designs.

MR MARCILLE: Well, let me elaborate. For example, a reactor coolant pump which is used to force the water through the reactor and steam generator, that reactor coolant pump requires not only the pump itself but piping and separate heat exchangers, separate control systems and control logic. So there's a whole series of equipment that attends a single system like a reactor coolant pump. By eliminating that reactor coolant pump or, in the case of the AP1000, four reactor coolant pumps and reactor coolant pump heat exchangers and control systems and the piping – all of that equipment has gone and is taken away, as for the SMR160 for example.

Other examples. The SMR160 uses passive circulation to cool for all time the small volume of spent fuel inside the containment. All light-water reactors in the world today require unlimited active cooling of the spent fuel while it's in the pool of the reactor building in order to ensure that it stays covered in cool. Those active systems again require investment and require power. The SMR160 eliminates that by relying on the intrinsic natural circulation modes and systems we articulated earlier.

MR JACOBI: I think right at the outset of your evidence you referred to there being different types of SMRs. I'm just interested in looking at the other SMRs that have been developed. Do they also adopt this approach of eliminating these features in order to manage their overall costs of electricity generated?

MR MARCILLE: In general they do. Not all SMRs eliminate pumps but all SMRs must look different than a scrunched down version of large light-water reactors if they have any hope of being competitive economically. So all reactor developers for small reactors are endeavouring to find ways to eliminate equipment or use innovative means to reduce the capital and operating costs of the plant, unless they serve a mission that does not try and resonate with the cost of electricity as the principal figure of merit. A military application, for example, may have mission surety as the critical figure of merit and costs may be incidental.

MR JACOBI: We've heard a lot with respect to SMRs, that one of the expectations of key drivers of economies is the manufacturability within a plant of their components. I'm just interested based on what you've just explained in terms of how you expect to manage costs the extent to which modularity is also seen to be an important feature.

MR MARCILLE: I would argue that modularity in the way that term has been used and the way modularity has been applied in the commercial nuclear industry is not applicable to SMRs. For example, if you look at AP1000s being built in Georgia and South Carolina today, the large modules are being erected on the site and the largest modules to go into the plant are an agglomeration of equipment that is erected within steel frames. The mass could exceed tonnes and, for the large modules, do. The small modular reactors are physically so much smaller that that field erection of that single large modular doesn't make sense. You'd have built the entire system at that point.

Factory manufacturing offers lots and lots of benefits of field manufacturing. You're not subject to elements of weather. You can work undercover. You can have round the clock shift. So the more of the costs that can be shifted into a controlled environment like a factory gives you a better opportunity to control the cost and the quality, but it does not mean that every SMR is naturally amenable to that type of concept or the ability to realise those savings.

Let me give you an example. If you look at the cost elements for large light-water reactors, capital equipment represents a certain fraction of the total capital or overnight costs of the plant. Craft and supervisory labour represents another significant part of the cost of the plant, raw materials, concrete, steel, piping, stuff like that. The SMR160 has cost elements that are radically different than large light-water reactors. The single largest cost element for the SMR160 is fabricated or engineered equipment. The single largest cost element for a large light-water reactor is craft and supervisory labour. So by engineering a different product, a small orange versus a large apple, we have the ability to reallocate costs in the case of the SMR-160 in to capital equipment. That capital equipment happens to be manufactured in the factory, so we move a larger fraction of the work in to the factory. It's imperative that the design specification is amenable to that. It's difficult for me to speak to other vendors' concepts or their designs but for the Holtec SMR-160 because so much of the cost is in engineered equipment, we're able to take advantage of factory fabrication of that equipment. And again, we're better able to control the cost of the plant because so much of the equipment is fabricated in the factory, so much of the cost of the plant and we are a capital equipment manufacturing company. That's what we do for a living. So it works for us because we're a fabricator.

MR JACOBI: Yes. We have also heard another aspect of cost is driven by the extent to which companies expect to have an order book of plants to manufacture and the extent to which they can enjoy economies of scale because they're manufacturing multiple versions of the same item. I am just interested to the extent to which your view of the costs of the Holtec plant depends upon a view of that?

MR MARCILLE: Yes. I would say that the second time you do anything you do it better than the first time. So the more you do it, the more you improve. I would also suggest that people who argue - even SMR vendors, that argue that the economies of SMRs can only be realised through a large order book to facilitate the fabrication of hundreds or even thousands of components, I would suggest they fundamentally don't understand. They may be designing little apples instead of little oranges.

MR JACOBI: Now can I just come to your view about the extent to which SMRs might enjoy a benefit one way or the other because of an expectation as to their lower upfront capital costs?

MR MARCILLE: Yes. If you look at – in the United States and in France and in Finland and even in the UAE, overriding cost estimates for large light water reactors range in the three to $5,000 range per kilowatt electric. Those are the reference estimates before those plants begin construction. If you look at the limited amount of data available for as built new large reactors, current projections run somewhere in the area of two to three times the capital cost estimates. So the French reactor in Finland, or the French reactor in France, or the Westinghouse reactors in the United States, the actual projected capital cost of those plants will exceed the estimates of those plants by multiples. That has a dramatic impact on the cost of electricity over the levelised life of the plant. The small modular reactors, the capital cost is substantially less and the construction periods for the small plants are substantially less, so variability in the cost of a small modular reactor has an associated less knock on impact on the levelised cost of electricity. If a large light water reactor has a projected construction duration of five years for example, and the cost and duration to construct that plant increases by a factor of two, that's two years of multibillion dollars of construction loans and interest – 10 years rather of interest payments and the cost of money. Small modular reactors can be constructed in arguably as little as two years, so a 50 per cent increase for example in the construction period of a small modular reactor would only increase the duration you paid interest on the construction loan to three years.

We've done sensitivity analysis that shows that for the SMR-160 changes in the capital cost of the plant increases in the capital cost of the plant have proportionally a much smaller impact on the levelised cost of electricity than do increases in the capital cost of large light water reactors because the capital cost of the large light water reactor is such a huge portion of the levelised cost of electricity from that plant.

MR JACOBI: I think that might lead us in to just in broad terms, where you see – given the current state of the development of the design, do you have a view about your ability at this stage to estimate the cost of electricity from your particular plant design?

MR MARCILLE: Absolutely. We're asked about that by potential clients all the time. Clients ask us to estimate not only the capital cost but the levelised cost of electricity as a function of the deployment model which they're interested in. For example a client may want one SMR-160 or may want four SMR-160s. A four-unit complex offers economies that allow us to use co-joined or shared non-safety portions of the plant, so we can improve the economies of a multi-unit complex relative to a single unit for example. Depending on the rules in play in the country where the plant will be located or if it is in a commercial versus a military application, can have big impacts with respect to the security staffing required; that security staffing, a portion of the O&M cost. So there's a lot of variables out there. We have ranges of the levelised cost of electricity for the SMR-160 that run between $75 a megawatt hour to $100 a megawatt hour, depending on the concept of the deployment model. Those numbers are very, very favourable compared to the projected reference cost for the large light water reactors and when you consider the exploding cost, capital cost, for large light water reactors, those numbers are absolutely fantastic.

MR JACOBI: Now inherent within those numbers, what is the view as to the likely construction time required for the plant that you're developing?

MR MARCILLE: Those numbers depend on an assumed three-year construction period.

MR JACOBI: And within that three years, is that three years from the point of a decision being made to build, once licensed, or what does that three year window include?

MR MARCILLE: That duration is the clock starts ticking when we achieve something called first safety concrete. So it's the physical construction duration of the plant to the point where fuel is loaded in the reactor and that duration has been estimated by our engineering construction partner in association with us in developing the solution. By the way, that engineering construction partner is the engineer of record, of nearly 50 commercial nuclear power plants in the United States today. So they have not only a pedigree but the experience to understand how to design and build and estimate commercial nuclear power plants.

MR JACOBI: I'm just interested, beyond the three years; we've had some discussion about the movement beyond a preliminary safety analysis to a final licensability. I'm just interested in your view as to – if you took the most optimistic view, and that is the Holtec were approached today by a country minded to develop such a plant, what's your view as to what a reasonable period of time might be before such a plant could be operating somewhere else in the world?

MR MARCILLE: Somewhere in the neighbourhood of seven to eight years from today. I look at the time necessary to complete the preliminary safety analysis report, submit – prepare and submit a construction permit application and then to simultaneously during the submission and review and the construction, once the permit is issued, the final safety analysis report – when I look at the three year construction period, that gets me out in the seven to eight year timeframe. That's the most optimistic timeframe.

MR JACOBI: And do you have a view as to – with reasonable contingencies, that is assuming that licensing takes longer or a view as to if construction were to take longer? What a reasonable range might be?

MR MARCILLE: The licensing question is just so open-ended. It would be virtually impossible and really disingenuous for me to suggest I'd have an answer to that. Countries have entered the commercial nuclear business of late and have come through the licensing process in a much, much more expedient manner than, for example, in the United States. It's not to say they did not do it safely; they took advantage of existing technology and existing process. But the licensing question and issue is the wild card. That's the most challenging issue right now for new reactors, whether it's light water reactors, gas reactors, liquid metal reactors, you name it.

MR JACOBI: And can I just pick up something I think we left up in the air and that is you spoke of the development of a testing facility in Camden by Holtec and I'm just interested in understanding the sorts of equipment associated with the plant that you're going to test at that facility and over what sort of time frame.

MR MARCILLE: We've hired a fellow named John Groom as the principal test engineer. John helped design and then actually built the APEX facility for Westinghouse, which was the integral test facility for the AP600 and AP1000. He also built and ran the test program for the NuScale Power plant. John is arguably the most accomplished and capable person in the United States to do this work. He is dealing with some partners of ours - the scaling analysis right now to allow us to begin construction of the test facility within about the next 18 months. It will be a half-height facility. It will be several megawatts of electrically heated power. It will run at full temperature and pressure. In addition, with an integrated facility it will allow us perform separate effects testing on the heat dissipator ducts and the steam generator.

Most integral test facilities are only concerned with the shutdown accident conditions. They're not designed to operate at full operating conditions. It's more expensive to do it that way. As far as the regulator is concerned, they're not particularly interested in normal operation, they're interested in knowing how the plant responds when there's an upset or an accident. We're developing this test facility to give us the ability to test and study the operation of the plant at full temperature, full power, full flow rates, as well as accident and upset conditions. So we will simulate through scaled equipment the operation of essentially all of the engineering safety systems, including the reactor, steam generator and pressuriser.

MR JACOBI: Over what sort of time frame is that testing expected to be carried out?

MR MARCILLE: A normal NRC design certification test program can readily be completed in 12 to 18 months. We see the test program being an ongoing campaign for longer than that as it gives us the opportunity to help people become familiar with the plant and to train operators. So the test facility will be there for a long time. The opportunities to evaluate the benefits of the test facility beyond that necessary for safety analysis testing remains to be seen.

MR JACOBI: I think we've got a schedule of the test facility - build schedule - on a slide. I'm just wondering whether very quickly you could take us through in terms of the time scale of what's shown as being done in the Gantt chart.

MR MARCILLE: As I indicated, we're doing the so-called scaling analysis right now which is an exercise which allows you to preserve the physical surface areas or volumes that are important within a system as a function of those important phenomena which you're hoping to study. The other parallel phase is known as the PIRP, the phenomena identification and ranking table process, where we convene groups of experts who are able to look at the system as designed and evaluate from their experience what are those things - pressure, temperature, flows - as a function of the design which are important to understand to be able to accurately predict the performance of the plant.

So the scaling analysis and the phenomena identification and ranking will all be done by the end of the first quarter of 2016. The development and deployment of the quality assurance program and the design of the facility would be completed by this time next year. We will procure and manufacture all of the hardware for the integral test facility within our manufacturing facilities.

Holtec currently has a factory on the east side of Pittsburgh which is approximately a million square feet where we design and manufacture pressure vessels, heat exchangers routinely. That's what we do for a living. So all of the equipment for the test facility should be completely fabricated, manufactured if you will, by the end of the first quarter of 2017. We show procurement occurring in calendar 2016 as well. Valves, for example, we don't design and manufacture ASME section 3 safety values. We will require valves - check valves, flow valves - electrically heated rods to simulate the nuclear fuel.

The construction for the test facility will occur in the second half of 2017 and the first half of 2018. We will do the shake-down testing some time in the middle of 2018 and commission the facility by the start of the third quarter of 2018. The test facility should be ready to go in its complete design fabrication, testing and shake-down, in approximately three years.

MR JACOBI: Then I gather the testing will then continue for a number of years after that.

MR MARCILLE: Yes. As I indicated previously, a nominal appendix for the test program of this nature can reasonably be executed somewhere in the 12 to

18-month period but we expect to use the test facility for lots of purposes that go beyond just validating the codes and methods for the plant. We want to study it and understand it better than anybody else. We also intend to make the integral test facility available to the US Department of Energy laboratories. We're designing it to be reconfigurable. So we're offering access to the test facility to the US laboratories so they can study and develop advanced codes and methods, multiphysics tools. This test facility will be unlike any facility in the world in terms of its operating modes and its reconfigurable characteristics.

COMMISSIONER: Thanks very much, Tom. Final question - can we just move away from SMRs. I'd because interested because of your background to get a view about where you think new generation reactor development is - how is that occurring in the US? What do you think is likely to happen?

MR MARCILLE: I believe that non-water technologies will in fact see the light of day. There's been a great deal of work over the years in gas reactors and liquid metal reactors. There's interest today in salt reactors. Certainly the most mature of those technologies is the liquid metal reactor. Liquid metal reactors have been designed and built and operated for decades in the United States, in Russia, in China, in India, in Japan and France. There's a huge experience out there. The integral fast reactor is a concept that's been under development by Argonne National Lab and now General Electric for some 20 plus years.

A reactor of that same design pedigree was called EBR-II ran for nearly 30 years in the United States. It was a 62-megawatt thermal sodium-cooled pool, metal fuelled reactor. It produced 20 megawatts of electricity and did so dependably for again some 30 years. In 1964 the EBR-II demonstrated the integral fast reactor concept whereby metal fuel bundles were removed from the reactor, were electro refined to separate the fission products and to enrich the fuel with fissile material, to refabricate the bundles and put them back into the reactor, and that all happened within a very, very compact space. That's where the name integral fast reactor comes.

Gas reactors are under development. There's small gas reactors, test reactors and prototype reactors under construction in China today. Germany designed and operated a number of reactors. General Atomics had a prismatic block gas reactor. We operated a commercial reactor in the United States using gas called the Fort St Vrain reactor. The English have obviously operated the CO_2-cooled advanced gas reactors for many, many years.

From a power density and from a safety and an extensibility standpoint, my personal opinion is the liquid metal cooled fast reactor is far and away more mature, more certain, more tested and improved, and offers extraordinary benefits for a world that looks for long-term options to dispose of transuranics.

Liquid metal fast reactors have the opportunity to burn those isotopes which are heavier than uranium, the actinides and transuranics, which create essentially all of the long-term radiotoxic problems that you have to deal with in a repository. When I say "burn", fast reactors will fission those isotopes, so the plutoniums and the americiums, those nasty players. It's a uniquely capable system to do that.

I struggle to see a path forward any time soon in the United States for fast reactors because the Department of Energy in the United States government has abandoned that for many, many years now. We shut down and took apart advanced fast reactors in this country. That being said, countries around the world - the Indians have commissioned a 500-megawatt fast reactor and have three more coming. The Chinese are building fast reactors. The Russians have been committed to them for many, many years and continue to move ahead. In my personal opinion, they offer huge promise.

COMMISSIONER: A final question, do you have a view about when we might see the first commercial one of these reactors in a sort of decade ballpark sort of figure?

MR MARCILLE: A commercial fast reactor?

COMMISSIONER: Yes.

MR MARCILLE: There have been many commercial fast reactors - - -

COMMISSIONER: Sorry, I was talking about the liquid metal reactors. When do you think the first of those might be commercially run?

MR MARCILLE: Commercial fast reactors have operated around the world for many decades now. The Russians operate commercial fast reactors today and are building a commercial fast reactor today. India is building large commercial scale liquid metal fast reactors today. The United States built and operated in the early days commercial fast reactors. It's not a question of the readiness or the availability of the technology. The technology is well-proven and universally understood.

COMMISSIONER: Thanks, Tom.

MR MARCILLE: Thank you.

COMMISSIONER: We'll adjourn. Thank you very much.

MR MARCILLE: You're most welcome. Thank you for the opportunity.

MATTER ADJOURNED AT 8.23 AM ACCORDINGLY