RESUMED **[12.30 pm]**

COMMISSIONER: We resume at 12.30 and I warmly welcome Professor Peterson from Berkley University in California. Counsel assisting.

MR DOYLE: Professor Peterson teaches courses on reactor technology and reactor safety amongst other topics in a nuclear engineering faculty at Berkley. He has a particular interest in regulation and licensing of nuclear reactors and has served in many advisory roles to government bodies and organisations in the United States in relation to nuclear safety issues. He's currently a member of the Diablo Canyon Independent Safety Committee which is responsible for the periodic review of the operational safety at the Diablo Canyon nuclear power plant.

COMMISSIONER: Professor, welcome and thanks for joining us. We might just start with a bit of a general question in terms of we're trying to understand, from a safety perspective, reactor design and what's happened over the years. So perhaps if you wouldn't mind starting with, at a very general level, what are the critical safety functions and the core philosophies involved in reactor design?

PROFESSOR PETERSON: That's an excellent question. So as with other complex technologies that have hazards, such as aircraft, such as chemical facilities, such as hospitals, where you're doing something that is beneficial but you could also do harm if you didn't do it well. It's important to systematically identify potential sources of hazard and in the licensing process, design and licensing process for nuclear power stations, one has to have a systematic approach to identify all possible sources of hazard within the facility and there will be a number of different hazardous materials that one needs to review and consider. One also needs to consider all of the potential operating modes, not just when you're producing power but for example, if you were refuelling a reactor. Now that comprehensive review is necessary, the unique hazards associated with nuclear power plants really relate to the radioactive materials in the reactor core that are generated under power operation.

The fusion process that releases very, very large amounts of energy from very, very small amounts of fuel, uranium, generates in addition to the heat, radioactive products. Fission – we call them fission – the principle important hazards that needs to be considered in the design of reactors in order for them to be safe. And so most of the core philosophy and principles associated with reactor safety relate to how to make the reactor itself safe. But we don't want to minimise the fact that you need to also pay attention to how you manage spent fuel and other radioactive (indistinct) hazardous materials in the facility. But for the purpose for today, I'm going to focus most of my discussion on the safety of the reactors themselves and in particular, on the safety of reactors in operation and reactors that experience transience or accidents, to assure that there's not a release of radioactive materials. So there's, I would say perhaps, five primary principles that one wants to think about for reactor safety and I can describe each of them briefly.

The first, as I mentioned, is that as was discovered in 1938, the fission reaction of uranium and other fissile isotopes releases multiple neutrons and in a critical reactor, on average, one of those neutrons will go on to cause another fission event, so that you can have a sustained chain reaction. The critical element in the design of a reactor from the perspective of that chain reaction is that it should be self-limiting. That is the natural response of the fuel if the fuel temperature heats up, should be to reduce the rate of the reaction. And this actually happens naturally with uranium fuel, if a reactor is designed properly because there's natural processes that will slow down the rate of reaction as fuel heats up, if a reactor is designed properly. And the light water reactors which are the current most widely deployed commercial technology and the most readily available technology, intrinsically, will shut down the chain reaction if they overheat. The types of reactors that were built in the Soviet Union that used a combination of graphite and water, do not share this characteristic. And the cause of the Chernobyl accident was actually a run away chain reaction caused by the willingness of operators to violate operating procedures and operate the reactor in ways that would make it unstable.

So this leads us to the next principle safety objective that underpins reactor safety, which is that while we know that a properly designed reactor, we can limit the rate of the chain reaction and shut down that reaction with very high reliability. Even after that reaction shuts down, the radioactive products from the chain reaction, from fission, the fission products, will continue to undergo radioactive decay and generate heat. And a critical safety function is to reliably remove that heat, preventing the fuel from rising to temperatures where damage can occur that could release radioactive materials. So because this function of removing heat reliably is of such high importance, and this was recognised very early on, in the 1950s and sixties when the first submarine reactors were being developed, very reliable systems to remove decay heat were developed. But at the time, the technology available to assure that they would have high reliability required the use of active safety systems. That is, redundant sets of pumps and power supplies and heat exchangers that could reliably inject water and remove heat.

The reason for this was much as with the Apollo programme, the fact that the mathematical models and tools were not very sophisticated and you could calculate the reliability of these active systems with high confidence. The issue with the active systems is that they can face what's called common-mode failure and this is the cause of the Fukishima accident. The flooding of the basements and the disabling of electrical power was the fundamental cause of the accident and the loss of ability to remove heat reliably, and then combined with other errors that were made during the course of the accident and a lack of preparation to manage, was a principle cause of the large releases. Subsequently, we've developed new reactor designs, such as the AP-1000 and such as light water or small module reactors that are now in the process of being licensed in the United States and these reactors do not rely on external sources of electrical power, external heat sense in order to reliably remove under emergency conditions, heat. Because they use what we call passive safety, or gravity driven processes to perform this function.

So the next element for safety is what we call defence in depth. And that is the idea that you should not rely solely on any single mechanism or barrier to assure that you will not release any significant amount of radioactive material in to the environment, should you have an accident, either due to some type of human error, or due to some sort of external event such as earthquake or tsunami. And defence in depth for water-cooled reactors, includes having robust fuel forms but also having primary system boundary and a containment structure that is capable of containing radioactive materials, even if damage were to occur to fuel in the core. So this defence in depth also then is important to integrate in to the design in all different dimensions of how we design. So all systems should have some defence in depth elements integrated in to them.

The other critical safety function that we do provide in the design of reactors is to protect the equipment that's inside the reactor from external events. This is the reason that reactors are placed inside very, very robust engineered strong structures that can exclude the effects of external events and that are designed to withstand very severe ground motion, if you have earthquakes as well. And the Lucas Height actual reactor in Australia provides a very good example of that. If you see it actually has a very robust steel structure that surrounds the reactor building, and that is designed to make it so that objects, including aeroplanes, can't crash into the plant and cause damage that would lead to radioactive release.

And then the final element is that while was take all of these measures to assure that reactors have a very low probability of releasing radioactive materials, and there will be new designs for reactors are even more robust in this perspective, it is important for us to still also have developed emergency response capability so that we can respond if radioactive materials are released by taking appropriate measures to protect public health up to and including evacuation around a plant site.

What we have found in communities that have reactors in the United States is that the additional funding that is made available because of the fees and taxes that the power plants pay results in the emergency response capabilities in those communities being very, very robust, and that provides some societal benefit because of the fact that emergency response is something that we need on a periodic basis when we respond to natural disasters such as fires and floods and severe weather such as hurricanes and tornadoes, and also when we need to respond to other types of industrial accidents such as chemical facility accidents.

So the core philosophy for reactor safety is to have many different mechanisms which contribute to the overall safety and which make it so that the failure of any one of those mechanisms is not going to result in any sort of substantial negative consequence. That would, I think, be a little bit long-winded, but the answer to your question.

MR DOYLE: Thank you, professor. I think you've already begun to answer the next question I had, but I wonder whether you could develop it a little further. To what extent have the nuclear accidents that have occurred since the advent of nuclear power resulted in developed thinking about some of those five safety philosophies that you've just mentioned?

PROFESSOR PETERSON: This is an outstanding question, and another really important element for any engineering systems is to have a culture which identifies problems and then makes effective corrective actions. So when we have accidents that are serious, the Chernobyl accident, Three Mile Island accident, and Fukushima accident being perhaps the most important examples, it's critical that we use the lessons that we've learned from those accidents to take actions that make it highly unlikely or impossible for that type of accident to be repeated again. So the Three Mile Island accident is an interesting - the first thing I'll do is I would treat the Chernobyl accident separately.

MR DOYLE: Yes.

PROFESSOR PETERSON: Because that really was a consequence of very different design and safety philosophy that existed in the former Soviet Union, and the design of reactors in the case of Chernobyl not only where they could have this kind of positive feedback and rapid power explosions causing severe damage to the reactor core, but also placing these reactors in buildings that did not provide any containment function so that when the accident occurred the material could be released directly into the environment. We learned a lot from the Chernobyl accident because of the fact that we were able to then observe what the consequences were over the years in terms of health effects and things of that nature.

The Three Mile Island accident was the first example of an accident that resulted from what we call internal initiating events, that is a combination of failures of equipment and human errors that led to the temporary disruption of the injection of cooling water into the core, and the set of errors that were involved are things which have subsequently actually been largely eliminated as potential initiating events through design changes and changes to the training of reactor operators.

So the accident was initiated actually because operators had been performing maintenance on pumps that are used at low power to push water into the heat exchangers called steam generators that remove heat from that kind of reactor, and after they had finished performing the maintenance they made the mistake of not opening the valves on the pumps, which is what we call a mispositioning event in which there's been vast improvements and human reliability procedures that have greatly reduced the frequency of this type of event. That said, reactors should be designed so that no single failure, either human error or equipment failure, can cause an accident.

In the case of the Three Mile Island accident, what happened was that when the reactor was shut down because of a turbine trip, these pumps that were supposed to operate to provide cooling water did not function because they were closed off, and therefore there was no water supply to the steam generators, and the pressure and temperature in the reactor system increased rapidly and then, as designed, the emergency core cooling system activated and began injecting water and everything was perfectly fine.

But the valve opened on what's called the pressuriser in order to prevent the pressure in the primary system from exceeding design values, and what the operators didn't realise is that when they had then established cooling with the emergency core cooling system, that this valve did not completely reclose, and so they actually misinterpreted level changes that were taking place and this caused them to think that they had too much coolant in the system rather than too little. They made a huge blunder, which was to stop the injection of coolant and actually remove or let down coolant, and this allowed the core to become uncovered and overheat.

Today all these reactors have instruments that directly measure whether water is in the core or not. They're called sub-cooling margin monitors, and so this type of mistake is not one that operators would make - monitor for whether or not the core has been filled by water. So the set of corrective actions that have taken place actually have included measures that have greatly increased the reliability of plants over the years, and this is important.

Then we get to the other class of accidents, which are those which we call externally initiated accidents, and the Fukushima accident was the first example of a reactor accident, a severe reactor accident caused by external events, and as everybody knows, a once in a thousand year earthquake that should have been within the design bases because thousand year return frequency is well within the frequency for which we expect reactors to be built, but in Japan there was an unwillingness to make changes even when new information becomes available.

So therefore correcting the vulnerability of these reactors to tsunami threat was never performed, even though the flooding caused by tsunami is particularly problematic because of its capability to do the common failure for active safety systems, and in this case to flood the basements and disable all of the emergency diesel generators as well as all of the battery supplies, and the severity of the earthquake and the tsunami had also disabled the power transmission system to bring external power to the plant site, and so they therefore entered into what we would call a station blackout.

They had still some capability to inject water into the reactors because each plant had one steam turbine driven pump, and they were taking steam from the reactor vessels and using that to drive these pumps to inject water. But that only worked on a temporary basis, and so when those steam driven pumps finally failed, and it varied from reactor to reactor how long that took, and one of the reactors used a condenser instead of a pump, the very first Daiichi unit 1.

But when those pumps failed, the Japanese had not prepared in advance to use portable equipment, as had been done in the United States after 911 when we had to think about the question of what would operators do at a plant if a large commercial aeroplane were to crash into a plant, and to disable the equipment needed for active cooling, because our plants also rely on that.

So the delays in implementing water injection and inventing of containments, the water injection ultimately they were able to establish water injection using fire trucks that were on site and they were able to inject sea water into the reactors and stop the progression, but this occurred too late from the perspective of severe damage to fuel, chemical reactions of steam with zirconium metal cladding leading to the generation of hydrogen, and then the other key issue was the fact that in these boiling water reactors, which are different from those that you would likely want to consider in Australia, but the boiling water reactors, energy building up inside the containment will cause it to pressurise and in this case by not doing controlled venting that would have filtered the release, they leak large amounts of hydrogen and fission products into the reactor buildings and this is in turn was the surplus of the explosions and the offsite release of radioactive material.

So the correct response whenever problems are detected involves a couple of things. The most important is to have a strong safety culture that rewards the recognition and reporting of problems. Here on the Independent Safety Committee we monitor the plants, Diablo Canyon's corrective action program.

Of course there have been no events as serious as an accident here, but what we want to do is to make sure that we're constantly monitoring for problems at much, much lower levels of safety significance.

For example, if a motor that is pumping water through the condensers of the turbines fails because of a failed temperature sensor monitoring the stator windings, which has happened, and this causes the plant to trip, to make sure that there is effective processes to identify the cause and then correct that problem, moreover to share that information with other plants around the country so that they can take similar corrective action, and the systematic process of whenever problems occur, of determining the cause, which can include not just the mechanical elements but also, say, deficiencies in training or deficiencies in the leadership as well, correcting those problems so that the problems are not repeated is a critical element of reactor safety and, if you think about it, safety for commercial aviation, safety in hospitals, identifying reporting problems and having them be corrected is fundamental.

What we see if you look at statistics for the United States was in 1970s and 80s nuclear plants in the United States had abysmal reliability. Any day of the week only about two-thirds of the plants would actually be operating and the rest would be shut down for a variety of different problems. It also varied a lot between utilities. Some utilities their plants were reliable, other utilities they weren't.

Systematically through the 1990s substantial improvement occurred in the United States, primarily because we deregulated electricity. That doesn't have anything directly to do with safety, but it became possible for plants that were performing very poorly and had no reliability to be sold. What was observed was when the plants were sold, uniformly within 18 months or so the capacity factors of the plants would raise from around 50 per cent up to about 85 per cent, and this was purely - it was not because the workforce had changed, instead it was because of changes in management and especially management philosophy around safety culture and encouraging the reporting of problems so that they can be corrected.

So there's a number of lessons that we have learned from these accidents which have occurred at these plants. I think one of the most important lessons is the value of how the methods for removing heat from reactor cores do not rely on external sources of electrical power and instead rely on natural or gravity driven processes to also have normal shutdown cooling which is active, uses electrical power, and the combination of those two things then contributing to safety of the new designs.

MR DOYLE: Professor, just picking up on that last aspect of the passive system and its protection against the loss of external power, are there any other aspects of a passive system which make it more safe or more reliable than an active system of cooling?

PROFESSOR PETERSON: Right. So the passive safety systems, there is a number of elements which make them attractive, and in my research group the major focus of our research has been on developing improved methods for passive safety. So through the 1990s, for example, in my research laboratory, we did most of the work studying how non-condensable gases like air can impede the condensation of steam, because in a reactor, in a light water reactor with passive safety, what you want to do is you want to supply water into the core where it can boil, removing heat, you need a mechanism to condense that water, that steam, back to water so that it can run back into the core and set up a heat removal power.

The thing that can impede the condensation is non-condensable gases. So much of the work that we did involved understanding the effects of non-condensable gases so that we could predict and prove that the passive safety systems could function with adequate heat removal capability under a wide variety of different conditions, and this was used in licensing of AP1000 and ESBWR.

So one of the major benefits that I see from having a combination of passive safety systems for emergency decay removal and additional systems for active heat removal, as well as another layer of defence, portable equipment that can be used to restore cooling functions as well, this is called in the United States FLEX equipment, is that the passive equipment because it's located inside this robust containment building structure it's difficult to get physical access to, and because we also need to make sure that nuclear facilities are physically secure against attacks by terrorists and also against insider type of efforts, having equipment which can provide removal of heat which is physically very, very difficult to disable, because it's designed to be physically difficult to get access to, it doesn't require a pump - pumps have to be inspected once per shift generally, right - so they're located in places that operators can get to very easily.

That, of course, if you think about it, obviously makes it easier for unauthorised access to be easy as well. So in my judgment one of the benefits of going to passive safety is that it improves physical security for plants also and it reduces the size of the guard force that you're going to need for a facility because the guard force size is going to be established by time motion studies, you have a design basis threat which will be an assumption about numbers of people who are trying to attack a plant, what their weapons and capabilities are, and that will determine size of your guard force. Your guard force will be much, much smaller if your safety systems look more like a bank vault.

So these are advantages of passive safety systems. Passive safety systems also have failure mechanisms, they're more susceptible to flow blockage. So if something unanticipated were to block flow, because the circulating forces are relatively low, you can impede heat removal, and this a principal reason why you want to have redundancy and diversity, and a part of the diversity that is good to have is some active systems that can also, with much harder driving force, drive cooling into the core. Again, perhaps a little bit like long-winded, but trying to answer the question.

COMMISSIONER: Thanks, professor. If I might continue with that theme about looking to the future. You have a lot of experience in the nuclear industry. I'd be interested in your view of what you think might be the most successful of the Generation IV technologies - and we'll ask you the million dollar question, when do you think those sorts of technologies might be commercialised and why?

PROFESSOR PETERSON: Okay. So of course. That is a very, very good question. Let me answer it sort of in two parts, because I need to divide the part which is sort of the policy framework, why we should be thinking about developing both small modular reactors which I think is an important next step, as well as why we need to be investing in the development of advanced nuclear technologies that don't use water as coolant. I cannot predict for sure, precisely which of these technical options is most likely to be successful, although I have strong opinions that drive my research programme and the things that I'm working on personally. But I think it's important to differentiate because in my judgment, the private sector has the best ability to make decisions about how to best design reactors to be more economic. So a couple of important statistics – we've been trying to study this question of what makes the construction of new nuclear plants expensive. And it's kind of shocking. I've done studies and I can forward if you'd like to see them, the simple spreadsheets, when we look at the total quantities of steel and concrete and copper, stainless steel, aluminium, the materials needed to build different types of energy infrastructure.

And so if you compare a conventional generation to advanced – generation to light water reactor, pressurised water reactor, like the Diablo Canyon plant that I'm nearby right now, two modern windmills, like the best is two megawatt, fairly large scale windmill and to a typical automobile, like say a Chevy Malibu, and if you take the prices for procuring bulk steel, bulk concrete, copper these things, the commodity prices that you can download from the internet and you multiply the quantities by these prices, to come up with the total amount that the materials cost, and then you look at how that compares to the price that you would pay today. So a typical nuclear power plant today, when you look at cost, you'll be told that you'll need to spend about $5,000 per kilowatt of capacity to get one built. And the ones we're building in the United States, the new AP-1000's are probably the – a bit more than that. The ones being built in China may be half of that but that's about $5,000 per kilowatt is the nominal number today. Of that $5,000 somewhere between 36 and $50 pays for all the materials. That is the materials are less than one per cent of the purchase price.

So the wind turbine, those materials are currently about 11 per cent of the purchase price. For the Chevy Malibu which is a pretty sophisticated piece of equipment, you can – I mean in the reactor, this is reborn concrete. This is not that sophisticated. The automobile, the cost of the materials used to build the automobile like a Chevy Malibu is somewhere around eight per cent. So the major question is what is it that makes it so expensive to convert these materials in to reactors versus other types of energy infrastructure? And I think that one of the fundamental things that did strategic (Video link interruption) in development of nuclear technology was to assume making reactors big (Video link interruption) less expensive, and by the time we got to a 1,000 megawatt larger, I think that we were eliminating the opportunity to introduce and prove and to learn from experience. Because we were building such small numbers and because each individual reactor was so enormously expensive, the conservatism that you had to take in terms of everything that you did, because anything that would not perform perfectly would be a problem, was enormous. So this is one of the key reasons why I think that either one wants to focus on reactor technologies, which are established and we know how to build them, AP-1000 being probably the best example of a passive plant design, albeit large, we know how to build them with pretty high reliability, as well as light water reactor SMRs.

There's another technology which I think really merits serious attention in this coming decade which is the concept of floating nuclear power plants, based on the big cylindrical – currently they're used to drilling rigs in very, very robust floating structures. MIT is working on this technology; we're doing some studies as well. The key thing is that in shipyards you can fabricate steel in to large structures at much, much lower cost and much, much more rapidly than we can do when we try to build things on land at a site. Even with modularisation in the construction on land, for the construction on land, there's – it still ends up being significantly more difficult and complicated than what's routinely achieved in shipyards. So this is another area of technology that – along with smaller reactors, that I think merits looking at, or using well-established larger reactor designs.

So that takes me then to the question of what about Generation IV? And where do I think the major opportunities are? The first thing to emphasise is that among the Generation IV options, they have different advantages and disadvantages. They provide different types of products. Some of them are very, very good at delivering heat at higher temperature which is valuable from the perspective of reduced water consumption because of more efficient power conversion, of the ability to produce alternative products. Some of them are very efficient in how they would use uranium or thorium as a fuel. Some of them have the capability to destroy waste, although all fission energy systems will generate some waste that will require geologic isolation. This is inevitable. We don't have technologies that can adequately recycle enough to completely eliminate the need for geologic disposal. And moreover, the scientific consensus that properly engineered and sited geologic disposal facilities can provide safe long term isolation for all nuclear waste is very, very high.

So then my personal interest and the major focus of my personal research has been on reactor technologies that would use molten salts as coolants and possibly even as solvents for liquid fuel. But currently the major focus on my research group is towards the use of fluoride salts as coolants. And the fluoride salts have a set of attributes that make them very interesting as coolants for reactors but these involve trade offs with other desirable features that the alternative coolants would have. The salts are chemically stable and because they have very high boiling temperatures, up above – closer to the melting temperature of steel, molten salt systems will intrinsically have very low pressure. And because they have very low pressure, they can use primary coolant (indistinct) relatively thin wall and lightweight.

In fact, this is the reason that back when people were really looking seriously at the development of reactors to power aircraft, which actually thankfully we never actually did because that would be – you don't want to put reactors in airplanes. But the performance requirements for a reactor that could be light enough to go up in an aeroplane and could deliver heat at high enough temperature to drive a gas brayton cycle; those are things that are very positive performance parameters for things that would be used on the ground as well. And the molten salts emerge as the most logical technology. So the aircraft reactor experiment that was built at Oakridge National Lab used molten fluoride salt with uranium dissolved in it as fuel. And it was a very, very compact lightweight low-pressure reactor. So at any rate, with the molten salts, they also have the chemical capability, if radioactive fission products are released from solid fuel, or if they're in the fluid fuel, the problematic fission products that Fukishima caused long term – caused the most – the largest problems, iodine and caesium, under the chemical conditions of molten salts they just get (indistinct) extremely difficult to mobilise, and so what we're concluding is that when you make this transition you can achieve your safety through more intrinsic characteristics of the reactors because of the physical and chemical processes that make it more difficult to mobilise radioactive material. Okay?

So these are some of the reasons that we have interest in studying these technologies, and in fact we've had researchers from ANSTO visit us here in the United States and some graduates students also. We have a graduate student that's currently helping us with benchmarking models for some of the codes for the salt core reactor technologies, and ANSTO has a collaboration currently with the Chinese Academy of Sciences where they're working also to develop thorium molten salt reactor technology.

So I think that the key thing is that the Generation IV technology does remain at least a decade to two decades in the future in terms of being administrated sufficiently for commercial deployment. But I also think it's an area where any country that envisions utilising nuclear energy would want to develop its own domestic capabilities to evaluate, perform research, perhaps even generate commercial designs and deploy these reactors.

Now, the other element about reactors, when you look at the Generation IV technologies that were deployed or were developed back in the 70s and 80s into the 90s, the same basic mistake of trying to make reactors really big was committed. So, for example, the French, their Superphenix reactor was enormous and it ran into significant reliability problems. So in Gen4, I think if Gen4 reactors, the initial commercial deployment focuses on small modular configurations, then it will be far easier to innovate and to develop these technologies more rapidly, and so our major focus is on develop these technologies for deployment as multi-unit SMR configurations, and this I think is the area where we're most likely to see rapid progress towards developing the Gen4 technologies.

COMMISSIONER: Just to finish that section, and thank you for that explanation, is it your view that molten salt reactors are the most advanced in terms of the pathway to commercialisation?

PROFESSOR PETERSON: So again I need to emphasise that as a researcher at a university my focus on the molten salt technologies comes from my own judgment that they're a substantial opportunity. I do think that as we get to smaller reactors we can compress the development time scale substantially because we can build prototypes and demonstrations at sufficiently low cost that you're willing to iterate a few times before you get to the final design.

The other thing is that we've been looking at other industries to try to find examples of better practice. So a very important industry to look at is biotech where the licensing process is a phased process and you can address key fundamental questions such as basic safety characteristics very early on with go-no go type of gates. To the extent that we can develop strategies for licensing new reactor designs in a similar way, that could have a very positive impact.

A couple of additional companies where there is, I think a number of important lessons to tease out regarding innovation are the rocket company SpaceX, and the electric car company Tesla. SpaceX went through a beautiful process to develop a small reliable rocket engine as its first step, and to test this rocket engine, what they called the Falcon 1, which was a rocket that used a single one of these Merlin engines and they had a smaller Kestrel for the second stage, and the start-up company formed by Elon Musk that successfully developed this rocket, was completely different from the approach that resulted in the Space Shuttle.

In some respects I would consider the Space Shuttle, which over its lifetime the launch costs for the Space Shuttle were $60,000 per kilogram, and the Space Shuttle had very poor reliability. Accidents with the Space Shuttle were catastrophic, and there's a number of reasons why the fundamental design of the Space Shuttle contributed to that. What Musk has done is essentially to develop a highly reliable relatively small rocket engine, and then use nine of them to power a much larger rocket that has therefore significantly higher reliability.

The Falcon 9 heavy will be three of these rockets coupled together, 27 engines, the outside tanks feeding all the engines until they're empty, then removing the first two stages and then the third one, the middle one continuing on is the second stage, which is, you know, sort of a brilliant approach that completely re-fenced the strategy for how to develop that technology.

Tesla also has a set of very good lessons that you can dig out, and so I think that - and this is a space where we'll see the most interest in innovation occurring in start-up efforts, developing smaller scale reactors. If you look at water cooled, light water, small module reactors, the company in the United States that has been the most successful and is advancing towards design certification is a start-up company called New Scale that was spun out of Oregon State University and got far enough along with a very novel reactor design where the entire - these are very small reactors that can be delivered, not just the reactor, but assembled with the containment vessel all in one unit, and just settle into place in a plant.

This is an example I think of the benefits of having innovation with smaller organisations as in biotech doing a significant amount of the initial development and then transferring these ideas to larger organisations, in this case it was Fore, which is a large, multi-billion dollar architect engineering firm that has acquired New Scale and has carrying the technology through to commercial deployment, and I think it's these sorts of strategies that will have the greatest potential to address this deficit that we've had in innovation and to find some way to arbitrage this huge difference in price for converting materials into nuclear power plants versus converting materials into wind turbines or automobiles. The companies that figure out how to narrow that gap will be highly successful.

MR DOYLE: Thank you, professor. I want to move now just briefly from the topic of design and innovation to safety and regulation. You've already mentioned I think that one of the revelations of the last 20 years was the link between reliability and safety, but I wonder with particular regard to your involvement in the safety committee that assists the Diablo Canyon facility, whether you have any insights into how safety culture and community engagement can be achieved at a local level notwithstanding that regulation might necessarily need to be federal.

PROFESSOR PETERSON: That's a very good question. So I think that there's a couple of really important points related to regulation. The first is that on the industry side it's really critical to have leadership from the board of directors on down that considers safety to actually be fundamental to the success of their business because virtually everything that a regulator wants you to do to make a plant safe also makes it more reliable and economic, and since there is such a large alignment to view regulation as being something that actually the major goals of regulation are things that you want to be competent in doing anyhow, and then of course there will still be burdens associated with regulation.

But to view it from that perspective so that you're proactive in doing the things that make sense from the perspective of making facilities reliable and economic, this is sort of a critical mindset and it contributes to the mindset of safety culture because fundamentally what you want to have is a culture and operation of these plants that incentivises the reporting of problems, so that they can get fixed. And that then has mechanisms by which you can make changes to procedures, technical specifications, licenses, where you identify things in ways that things could be done better to make them safer. So the other element around regulation is that oversight can be valuable to a business. In some ways, you can think of oversight as being quality control and validation.

So for example, in the United States it’s uncommon for plants to have an independent safety committee likes ours. I’ll come back to that in just a second. But of course nuclear power plants in the United States are regulated by the US Nuclear Regulatory Commission which has statutory authority to issue licences and to take licences away and to issue fines and that develops regulations and the NRC monitors the operation of the plants. When the NRC monitors, one of the ways that they judge whether or not the operator has good safety culture is to look at how many problems are being self-reported and entered in to the corrective action programme to be fixed, versus how many problems are self-revealing. That is, something breaks that shouldn’t have and they have to go in and fix it. Because the evidences from safety culture is that people – that your self-reporting problems. So we have the NRC.

On top of that, in the United States, after – actually before the Three Mile Island accident – no, it was shortly after the Three Mile Island accident, the Institute for Nuclear Power Operations was formed which is an industry group that independently reviews operations, maintenance, engineering of all plants and it involves peer review. So INPO takes the best people from one plant and brings them to evaluate different plants. The INPO also is the organisation that manages the sharing of operating experience between plants. So any problem that occurs in a plant will be transmitted to all the others so that they can evaluate whether some similar problem might exist. And INPO issues rankings for plants and the interesting thing about those rankings is that the insurance companies use those rankings as the basis to set their insurance premiums, which creates an incentive for the plant management to work to do a very good job with respect to INPO, which is the reason why all of the plants in the United States have a third evaluation body which is normally called the Nuclear Safety Oversight Committee. Its job is to assess all of these different areas of the plant operation and report back to the CEO of the company how the plant is doing.

So that the CEO has an independent source of information about whether the plant is being run well and safely, that they can use to judge whether they're really prepared for the NPO and the NRC inspections and whether they are properly – whether the financial interests of the company are properly being addressed. And then the interesting thing about the independent safety committee, it was formed back in 1990 when California's public utility Commission did something very novel, which was to tell PG&E, Diablo Canyon plants were not running particularly reliably, did not have particularly high capacity factor back in the mid-eighties. And they told PG&E that rather than getting just a 100 per cent rate recovery, that they would come up with a deal where PG&E would be paid a certain amount per kilowatt-hour and if PG&E could improve the reliability of plants, they could actually recover all of their development costs. So they have an incentive to try to increase capacity factor.

The concern was that PG&E would cut corners and so part of this deal was the creation of this independent safety committee and we do not have any regulatory authority but the three members of our committee, and you can see our website dcisc.org, the three members, I'm appointed by the Governor, so Gerry Brown. We have another member who is appointed by the Attorney General and a third member who is appointed by the California Energy Commission and we serve three-year terms and so reappointments occur for one member every three years. And our job – we maintain a list of about 200 different things that we monitor at the plant. We hold public meetings three times a year, like the two-day meeting I'm at right now. And then in the intervening period we take three trips, one each month to the plant for what we call fact-findings, where a member and a consultant go to review items on this open items list. And when we hold the meetings, public meetings in particular, we discuss what we found and we identify if new issues emerge, or if public raises concerns, we will add items to this open items list and investigate it. Then we issue a very large report, with all of our conclusions related to safety of the plant. The key thing here is that while we only make recommendations, because our recommendations go to senior state leadership, Pacific Gas and Electric has always been responsive when we make recommendations for logical reasons.

I think that there's another example where the same sort of independent technical advisory group, they have a major success and that would be the Waste Isolation Pilot Plant which was built in southern New Mexico as a geologic disposal facility for waste from US weapons programme, Transuranic Waste. In the process of designing and licensing that facility, the Department of Energy which was responsible for doing that work, had the brilliance – they already had a supportive local community in Carlsbad that had a lot of experience with mining potash and therefore were very comfortable with the idea that they could develop a mine repository in very thick bedded salts that they had there. So the Department of Energy funded an independent scientific group that the state chose to locate inside its state university system and the scientific staff of that group reviewed all of the technical issues associated with the repository design and reported back to the state government on their findings. And I think for the political leadership of the state, having the ability to have somebody independently provide a technical assessment on the technical issues was very, very helpful ultimately in being able to make the necessary political and regulatory decisions that led ultimately to this facility being successfully opened and entering in to operation.

So in my judgment, within the field of nuclear energy and nuclear reactor safety, it's really critical to set expectations for high levels of transparency and to encourage extensive questioning attitude and review because that's the mechanism by which you can have early identification of problems and effective corrective action, so that the systems can be sufficiently reliable. The safety is acceptable and then you can benefit from the fact that fission energy provides very large amounts of energy from very small amounts of material.

MR DOYLE: Thank you, professor. Just one final topic, in considering the possible establishment of a power generation industry in a new jurisdiction, there's obviously a potential issue around human resources and expertise. Do you have any particular observations about how a new participant would address that potential lack of expertise? In particular, in staffing the regulator?

PROFESSOR PETERSON: Right. Well, you know I'm a university professor, so I have a strong bias towards education and training. So I think that there's a number of different things that one needs to do. One thing that I would advise is in strengthening your regulatory system, you already of course have the capacity to regulate nuclear reactors and the use of nuclear materials because you have a research reactor at Lucas Heights and also of course, you have extensive activities in the uranium mining as well. But to expand that capability to be sufficient to be able to regulate civil nuclear energy facilities, will require some investment. And the – one of the case studies that I would recommend looking at it is the United Arab Emirates who developed a regulatory capability so that they could import reactors from South Korea. What you will find is that that involved hiring a lot of retired Nuclear Regulatory Commission staff from the United States to come and assist in setting up that regulatory structure that they now have in the UA.

So one element will be establishing that regulatory structure. It could very easily require some legislative actions to develop or modify your statutes that create that agency. One of the things that I would consider in doing this is the value of creating an independent agency similar to the NRC. The Nuclear Regulatory Commission is not an executive branch agency of the United States. Instead it's decisions are made by a Commission that has five commissioners who serve terms of five years and who can only be removed for cause, whereas an executive branch agency, the secretary or the director serves at the will of the president and always gets removed when a new administration comes in and replaced with somebody else.

So you have, I think, more political influence over regulatory decisions with that model than with the independent agency, and the principal reason that the agency needs independence comes back to the vital importance of safety culture. In other words, you will not be able to have problems reported if the regulator does not have sufficient independence to be able to say, "We have an industry that is reporting hundreds of problems every day at their plant," which is about the number of notifications which will be filed into the corrective action program of a typical plant on any given day.

Of course, the vast majority are quite minor such as light bulbs needing to be changed and that sort of thing, but you will have hundreds and hundreds of notifications, large numbers of problems being reported, and the regulator has to be able to say the vast majority have no safety significance, because otherwise you can't get problems reported so that they can be corrected, and I think that that's one structural element that's really necessary, it's a societal contract.

For any complex technology, if you want to have safe health care, you need to create an environment where hospitals, where the staff are encouraged to report problems, even if it's embarrassing, right, and if you want to have safe commercial aeroplanes, you need to have a system where maintenance workers will report problems or if they hit a point in their procedure where you really don't know what to do, they don't do the work around something but instead they stop work and get guidance and maybe even get the procedure modified. That's really critical.

The other element is in terms of building up the base of engineering capacity within the university system. A couple of mechanisms for doing that would be, for example, to provide scholarships to students to pursue graduates, that is, more internships at universities in the United States, for example, as well as potentially internships with industry, so that you can build up this competence and this understanding of particularly some of the modern approaches to understanding safety, and to fund some research internally so that your universities can begin to do things such as work to perform experiments and to validate models for passive safety systems using integral and separate effect tests, and to begin to contribute to technical conferences in the areas of reactor safety nuclear fuel cycles.

These would sort of be essential elements of standing up the capacity to competently regulate this technology so that you can have confidence that it will operate safely and provide the benefits of affordable, low emission electricity generation.

COMMISSIONER: Professor, that's an ideal time for us to conclude. Thank you very much for your evidence. We very much appreciate you spending the time with us.

PROFESSOR PETERSON: It's been my pleasure and I also admire the work that you're doing. I have to say that the sophistication of the questions that have been posed to me has been quite impressive, so it indicates to me that you are already well along in establishing an understanding of what the technical issues and regulatory and safety issues are associated with nuclear energy technology, and I have to say I admire your effort because of that. So I wish you the best of success in your studies and in reaching determinations about advice for policy makers.

COMMISSIONER: Thank you very much. We'll adjourn to 1430 when the Australian Nuclear Science and Technology Organisation will provide some evidence.

PROFESSOR PETERSON: Very good. Thank you so much.

COMMISSIONER: Thank you very much.

ADJOURNED **[1.36 pm]**