COMMISSIONER: Good morning. The public session today is on nuclear reactor safety and regulation. We have experts from Canada, the United States and southern Australia and from a local company who is expert in risk. Mr Jacobi is enjoying his second week of planned leave and I welcome Mr Ben Doyle to read the context statement for today.

MR DOYLE: Thank you, Commissioner. The terms of reference require an inquiry into the safety risks to both the environment, the community and workers as well as the general public associated with the operation of nuclear reactors. Today's session will explore these issues at a general level before the Commission focuses tomorrow on the accident at Fukushima Daiichi in 2011 and the impact it has had on the development of design principles, safety assessment procedures and regulatory oversight.

This public session aims to explore the nature of the risks associated with the process of generating electricity from nuclear fuel, and the means by which those risks are sought to be mitigated. The Commission will hear evidence concerning the risks arising from the normal operation of nuclear reactors and in the context of an accident resulting in a shut down of the reactor. These risks include not only the immediate consequences of any exposure to harmful emissions, but the broader social consequences that can follow from emergency responses.

This public session aims to explore the ways in which developments in different reactor designs have sought to address the essential safety risks involved in the operation of a reactor. There will be a focus on those reactor designs and technologies that would be most likely to be investigated as part of any future development in South Australia. The experience of the nuclear industry has demonstrated that the operation of a reactor involves the management of a low probability but high consequence risk and risks of this kind pose their own unique challenges. They require comprehensive and ongoing analysis long after the design of a reactor has been completed.

Today's session also aims to understand therefore the conditions which are necessary to create and maintain an industry which fosters a safety culture and a regulatory regime which is robust, despite the challenges that can face the regulator of an industry in which there may be few participants. This will involve consideration of the different philosophical approaches to risk management including deterministic and probabilistic safety assessments and the ALARP principles which focus on ensuring that risks are reduced to a level which are as low as reasonably practicable.

The first witness to be called by the Commission in relation to this topic is Dr Gordon Edwards. Dr Edwards is the president of the Canadian Coalition for Nuclear Responsibility, the CCNR, which he co-founded in 1975. CCNR is a not for profit organisation dedicated to education and research on all issues related to nuclear energy, especially those pertaining to Canada. He has devoted over 40 years of research into nuclear activities in Canada and throughout this period has provided consultancy services to government and non-government bodies in relation to nuclear safety issues.

COMMISSIONER: Dr Edwards, thank you very much for joining us this morning. Can I start with a broad question, and before we address the risks associated with the operation of a nuclear reactor, can we begin to understand the two processes within the reactor which result in the generation of nuclear energy and the differences between them.

DR EDWARDS: Yes. Mr Commissioner, every nuclear reactor really is a boiler. It basically boils a lot of water to produce steam so that we can spin a turbine to generate electricity. The difference is that instead of burning a fossil fuel such as coal or oil, we obtain the energy by the splitting of uranium atoms. This is called nuclear fission, and it's this process which can be controlled by controlling the neutrons, these are little sub-atomic particles which are projectiles that cause the splitting of the uranium atoms, and by stopping the flow of those neutrons you can stop the reaction from happening, by slowing them down and reducing the number of them you can reduce the power of the reactor, or you can also have a situation where the number of neutrons increases rapidly, in which case you have what's called a power excursion, a rise in power which may or may not be planned.

So that's the fission process, and the nice thing about the fission process is that it can be shut off very rapidly. It can be shut off in emergency conditions within two seconds quite handily and, in fact, in most of the accidents that people have heard about, such as the Fukushima accident and the Three Mile Island accident, these, in fact, the reaction was stopped very, very quickly. But there is a second problem, and that second problem is radioactivity.

Radioactivity is a form of nuclear energy which cannot be stopped, there is no scientific way of stopping it, and it is a spontaneous process whereby the nucleus of a radioactive atom disintegrates suddenly and violently, giving off energy like shrapnel you might call it, sub-atomic particles that are given off with very great speed and nobody knows how to stop this process. Now, the complication is that by splitting the uranium atoms we create hundreds of new radioactive materials that were not previously present in the fuel and these hundreds of radioactive materials are very unstable, very radioactive and they generate by themselves sufficient heat to melt the core of the reactor even though the fission process may have been stopped, and that is what caused the meltdowns at Fukushima and at Three Mile Island, it was that residual radioactive heat that was unable to be stopped that caused the melting of the cores.

MR DOYLE: Dr Edwards, you have mentioned that the process of emission of radioactive particles from fission products, I want to come back to that in a little bit more detail in a moment, but are there two other sources of radioactive materials that can be created within a reactor?

DR EDWARDS: Yes, that's right. We mainly think of the fission products which are the broken pieces of uranium atoms, because they are responsible for most of the heat that is generated by - it's called decay heat. There are, however, activation products. Activation products consist of nonradioactive atoms which absorb neutrons and become destabilised and therefore radioactive. So things which were not previously radioactive, become radioactive.

For example, in the CANDU reactor which we have here in Canada, we use a moderator which is a nonradioactive form of hydrogen called heavy water. It so happens that heavy water is just like ordinary water except the hydrogen atoms are twice as heavy as usual, they're not radioactive, they're just a little heavier. Now, when a neutron is absorbed by one of these heavy hydrogen atoms, it is transformed into an atom which is three times heavier than normal and that's called tritium, it's radioactive hydrogen. That's radioactive, it has a half life of about 13 years and it is a dangerous by-product of the process, it's called an activation product.

There are many dozens of activation products created in the core of the reactor. The steel components, for example, generally have small amounts of cobalt in the steel, nonradioactive cobalt called cobalt 59. When the cobalt 59 absorbs a neutron it becomes cobalt 60 which is very dangerous because it gives off intense gamma radiation which can be quite harmful to workers or anybody else who comes into contact with them. In fact, cobalt 60 is also used as a cancer therapy device because it's very good at burning cancerous tissues that would otherwise cause the death of someone.

So the cobalt therapy is taking advantage of that damaging gamma radiation. But these are activation production and what this means is that even after the irradiated fuel has been removed from the reactors so that all the fission products have been taken out fundamentally, you still have the structures themselves being radioactive due to the activation of the materials so that even the materials inside the core of the reactor will become radioactive waste. They too will have to be buried or stored as radioactive waste for very long periods of time. Once again the fundamental factor of radioactivity is that we don't know how to shut it off, and that's why we have a radioactive waste problem.

MR DOYLE: Well, can we move now - - -

DR EDWARDS: There is - I'm sorry. There is a third process that I forgot to mention.

MR DOYLE: Yes.

DR EDWARDS: The third process is called - well, it doesn't actually have a name, but some of the uranium atoms that absorb neutrons do not split. There's one kind of uranium atom which splits. It's called uranium 235. There's another type of uranium which doesn't split when it's struck by a neutron, but it becomes heavier and transforms into a heavier than uranium element which is called plutonium. Now, not only plutonium but by absorbing more neutrons you can get other so-called transuranic elements heavier than uranium: americium, neptunium, plutonium, curium, and several others.

These substances have - they are also radioactive, but they have very, very long half-lives. They generally tend to have half-lives in the thousands or hundreds or thousands, or even millions of years, and as a result they contribute to the very long-term hazard of radioactive waste so that we can't just wash our hands of it after a few centuries. We have to actually look after it for literally hundreds of thousands, even millions of years for that reason.

MR DOYLE: Is it right they tend to be the alpha emitting materials?

DR EDWARDS: Yes, that's correct. Lighter elements generally do not give off alpha radiation. Alpha radiation is a form of radiation that most people would find peculiar. It's a non-penetrating form of radiation which is nevertheless highly damaging. You can stop alpha radiation with a piece of paper. Just put up a piece of paper in front of your face and it will stop all the alpha radiation coming off from an alpha emitter. However, if that material gets inside your body and the alpha radiation comes in direct contact with living cells, it's known to be far more damaging inside the body than gamma radiation or beta radiation, which are more penetrating. So the curious paradox is that even though it's less penetrating, it's much more harmful.

Now, there's a phrase used called a becquerel. A becquerel refers to one radioactive disintegration every second. It's a measurement of radioactivity. Each becquerel of alpha radiation is about 100 times more damaging, biologically damaging, than a becquerel of gamma or beta radiation. The reason we talk about becquerels is because radiation is actually energy coming from the core of the atom, and it's very sudden. It disintegrates. The atom disintegrates, and when it disintegrates that's when it gives off either a highly electrically charged particle, which is called an alpha particle or a beta particle, or a burst of energy called a gamma ray.

The gamma ray is what most people think about because it's analogous to x-rays, and so most people when they think of a radiation, they think of some kind of invisible ray that you've got to get away from. But in fact when you're talking about alpha radiation and beta radiation, that's an inappropriate thought. You shouldn't think about it as a form of penetrating radiation you're going to have to escape from. You think of it as a pollutant, much like a chemical pollutant, something that would get into the food or into the water or into the air so that you inhale it or ingest it, and once it's inside your body, depending upon the chemistry, it could be incorporated in different parts of your body.

For instance iodine 131 is incorporated into the thyroid gland. Strontium-90, which is also a fission product, doesn't exist in nature. This gets incorporated into the bones and the teeth and mother's milk because it's similar to calcium. Something like caesium-137 is similar to ordinary potassium, so it goes to the blood and to the soft organs, and that's why it's a danger for agricultural - people who are growing, for example - or just to give you a particular example, in Northern England even 20 years after the Chernobyl accident in the Ukraine there were sheep farmers who couldn't sell their sheep meat for fear of caesium contamination, radioactive caesium contamination from the Chernobyl accident.

Radioactive caesium is not a naturally occurring material. It only occurs because of the splitting of the uranium atom either through an atomic bomb or through a nuclear reactor. So this material has about a 30 year half-life, caesium-137, so it stays in the soil for a long time and it gets incorporated into the grass that the animals eat, and then gets incorporated into their meat, and it doesn't go to the bones, it goes to the meat, the soft organs, and that's why it poses problems for restrictions on agricultural meat products that can't be consumed safely. So they have to keep careful watch on that.

This is the fundamental problem with nuclear safety. It's not the machine that's dangerous. The machine is really not dangerous. What's dangerous is the enormous inventory of radioactive materials inside the machine, and if there's anything, whether it's a comet from outer space, or an aeroplane crashing into a nuclear reactor, or some kind of industrial accident including explosions, anything that will breach the containment and allow this radioactive material, the fission products and the other radioactive materials, to escape into the environment could have catastrophic results, and that's what makes nuclear power plants dangerous. It's not the machinery. It's the nuclear waste inside.

MR DOYLE: You've mentioned, Dr Edwards, the possibility of external events breaching containment. Can we come back to I suppose what might be a more stereotypical risk of emission of radioactive materials and the process of controlling decay heat following a shutdown. I wonder if you could explain the basic potential problem that is involved once the criticality has been controlled but the radioactive material continues to produce decay heat.

DR EDWARDS: Yes. That's one of the fundamental problems. There are really two types of severe nuclear accidents. One involves a situation where the actual fission process gets out of hand. That can happen and that's why you need to have very rapid shutdown systems. The difficulty with the chain reaction, as it's called, of fissioning uranium atoms is that the neutron population suddenly starts exploding, then you have a real explosion. The core of the reactor could self-destruct and blow the containment - damage the containment in such a way that the radioactive inventory has a pathway to the environment, and that's why you have a serious accident of that sort.

Another type of accident, however, and one that is more likely is if you do successfully shut the reaction down, and they have very fast shutdown systems which are tested regularly and which are hopefully always going to be reliable, then you have to cope with what's called the decay heat, and that's the heat that's generated by the nuclear waste. Now, if you don't have any damage to the plant, it shouldn't be a real problem. You just keep the pumps running, and if you keep the pumps running then just like before the circulating water removes the heat as fast as it's produced, or even faster than it's produced, and everything is safe, everything is fine. However - - -

MR DOYLE: Before you go on, Dr Edwards, how does the quantity of the decay heat typically compare with the quantity of heat that's produced during fission?

DR EDWARDS: Well, during fission full power heat - for example if we had 1,000 megawatt reactor let's say, then the amount of heat that would be produced would be 3,000 megawatts. It's about three times as much as the electrical output. So two-thirds of the heat actually is waste heat. One-third of it goes to generate electricity. So you have about 3,000 megawatts of heat being generated at full power. The moment that you shut the reactor down and stop the fission process, the decay heat is about 7 per cent of full power, and that declines rapidly, so that after about four hours it has declined to about 1 per cent of full power.

However, even 1 per cent of full power is more than enough to melt the core of the reactor, and people at this point in the discussion, people have to realise there's a difference between temperature and heat. Temperature is just a measurement of how hot something is. Heat is a form of energy, and if heat is being generated, then the temperature will go up so that although the fuel is originally at a safe temperature, if that heat is not removed, the temperature will go up and up and up, and it reaches the melting point at about 2800 degrees Celsius. That's the melting point of the ceramic fuel, the ceramic fuel pellets which is, by the way, much higher than the melting point of steel so that once the fuel melts at that temperature, it will tend to melt through anything else as well unless you can somehow prevent it from doing so. So the important thing here is to have a steady supply of cooling water that can remove that decay heat as rapidly as it's being produced. And the decay heat declines rapidly and it becomes more and more manageable as time goes on. Nevertheless, even after the fuel is removed from the reactor, it has to be put in to a pool, a spent fuel bay which still has to have circulating water in it for – in Canada here, we require it for 10 years. You have to actively cool the irradiated fuel for over 10 years just to prevent it from overheating. If you were, for example, to interrupt the cooling, even in the spent fuel bay, it wouldn't melt down but it would overheat and damage the metal cladding on the outside of the fuel and you would have a release of some of those radioactive materials, including the radioactive gases.

There are about 20 per cent of the fission products are actually radioactive gases, they're called noble gases because they don't chemically combine with anything else. There's radioactive isotopes of xenon and argon and krypton and those things are gases and so they will escape as soon as there's any defect in the fuel cladding. There's also elements such as iodine and caesium, radioactive iodine, radioactive caesium which very easily sublimate from a solid radiant to a vapour and those vapours are also given off at elevated temperatures. So although you won't have a meltdown in the spent fuel bay, you will have damage to the fuel, self-inflicted damage to the fuel and releases in to the environment. And as we've discovered in recent years, is that up until the present time, we have not really taken adequate care to have shielding around the top of the spent fuel bay. In other words, the spent fuel bay is not within the containment of the reactor. Consequently the spent fuel bay is more vulnerable to atmospheric releases.

One of the things they were concerned at, at Fukishima in unit number four was the spent fuel bay, which was open to the atmosphere and had you had a serious overheating of the fuel, then you would have had direct releases to the atmosphere which is actually not the case with the fuel in the reactor core because it is more shielded. It has various multiple containment systems. So it's not so easy to get out. Yes, so - - -

MR DOYLE: Can I come back at this point? Sorry to cut you off Dr Edwards - - -

DR EDWARDS: That's fine.

MR DOYLE: - - - to the means by which a loss of removal of decay heat within the - - -

DR EDWARDS: Right.

MR DOYLE: - - - reactor, can result in a breach of containment? Is it simply through the heat reached by the fuel that's melted and potentially leached to the bottom of the reactor vessel, or are there other pathways?

DR EDWARDS: Well, in itself the – even severe damage to the fuel does not necessarily result in a breach of containment. However, there are other mechanisms at work which can result in a breach of containment. For example, when you get the overheating of the fuel, you get – because there's water as a coolant in the reactor building, you get a lot of steam produced. And at those temperatures, we're talking here about 1,000 degrees Celsius, not up to the melting point yet, but beginning at around 1,000 degrees Celsius you get a very energetic reaction, chemical reaction between the zirconium metal, which is the cladding of the fuel and the steam. And what happens is the zirconium metal oxidises very rapidly and releases hydrogen gas. Hydrogen gas, as you know is very explosive. And again, we saw this at Fukushima, three violent explosions which were really hydrogen gas explosions caused by the interaction – the chemical interaction of the zirconium metal with the steam, resulting in any kind of little spark will – once it reaches a certain concentration can cause an explosion. That of course – and the worst circumstances could breach containment.

Interestingly enough, at Fukishima, although it damaged the outer building and resulted in some releases of radioactivity, we're lucky that it did not actually breach the main containment vessels, so that in fact most of the melted fuel at the Fukishima reactors did not get released in to the atmosphere through that. It's only the stuff that had been released, along with the steam, that's the only material that escaped. So that's why the Fukishima accident was not considered to be as disastrous as the Chernobyl accident. The Chernobyl accident you had a complete loss of containment.

MR DOYLE: Thank you.

DR EDWARDS: Now there was one thing about the Chernobyl accident, this is another mechanism. What happened at Chernobyl was that they didn't have a fancy containment system like they did at Fukishima and the roof of the building got blown off. But one of the features of the Chernobyl reactor is that when you lose the coolant, that is if there's a pipe break or anything that loses the cooling water, then at that moment, two things happen. First of all, the water is so hot in the primary coolant system, it's about 300 degrees Celsius or more and the only reason it's still water is because of enormous pressure. It's pressurised so that it cannot boil. As soon as you have a break in the pipe, all that overheated water turns in to steam, so you get a steam – flashes in to steam, which creates a great deal of steam pressure inside the building. But at the same time, you get an increase in the power level; you get a spike in the fission process. This is called a positive void coefficient of reactivity and it only applies to certain designs of reactors, including the CANDU reactor. It turns out that any reactor which uses what are called pressure tubes instead of a pressure vessel, this is a bit technical. But basically the American design and the French design, basically they have one big boiler which is called a pressure vessel, and the fuel is inside this pressure vessel and the water circulates through that vessel. In that case, if you have a loss of coolant, it does not result in a sudden power increase. But in the CANDU design and in the Chernobyl design, you have individual tubes, pressurised tubes that are called pressure tubes, containing the fuel, and when you lose the coolant in those cases, you do get a power surge at the same time. And so this makes it particularly hazardous to make sure that that power surge is not going to overwhelm the shutdown systems.

There was another accident in Switzerland in 1969 at the Lucens reactor, a research reactor which was also a pressure tube design, which had the same type of situation where there was a loss of coolant, an immediate power surge and the reactor blew itself to kingdom come basically and destroyed itself. And that reactor was first of all sealed in a rocky cave and then eventually disposed of. But that is an unusual safety concern that caused the CANDU designers, the Canadian designers to insist upon two fully independent shutdown systems. Other reactors in the world do not have this. But the CANDU system has not one but two fast shutdown systems to mitigate against this type of situation. So that if the one shutdown system for some reason would not work, the other one would hopefully and there we have it. So there are differences in design. But the fundamental problem remains the same. How to stop the stuff from getting out? Now if the containment holds and you don't get atmospheric releases, or at least not substantial atmospheric releases, then the next problem is what if it melts down through the bottom because when it melts down, it can just keep on melting and if you get a complete core meltdown as you did at Chernobyl then the fuel just melts its way through the concrete base and in to the ground and then you have the problem of contamination of groundwater, and possible steam explosions.

Steam explosions are not fully understood as a matter of fact. It's not just due to steam pressure, it turns out that when very hot molten metal falls in to a pool of stagnant water, you get a very powerful physical explosion called a steam explosion, which is not the same as a steam pressure explosion. And that can in fact damage the containment above and lead to atmospheric releases. The worst thing of course is to get the atmospheric releases, at least in the short term. But you have that longstanding problem which they still have at Chernobyl to this day, what to do about the stuff that's all melted down in to the ground. And of course at Fukishima they haven't begun to address that.

MR DOYLE: Dr Edwards, you've mentioned a couple of aspects of the

CANDU reactor design that give rise to potential issues. I wonder if we could just take briefly, a step backwards and if you could explain the basic technological difference between a CANDU reactor and a typical light water reactor.

DR EDWARDS: Yes. Well, the main difference is the one I mentioned to you, is that the light water reactor uses a boiler, basically a large pressure vessel, very thick, very thick hold as it were, to contain all the pressurised water. Now, there really are two types of American design. So there's the pressurised water reactors which are more like the CANDU because we also have pressurised heavy water reactors, and then there's the boiling water reactors.

The boiling water reactors - and Fukushima was a boiling water reactor - there the water in the core is allowed to boil and that steam is used to turn a turbine, whereas in a pressurised water reactor they separate those two systems. They have one system which is pressurised and does not - basically it's a closed loop, it just goes around and around and delivers its heat to something called a steam generator, and there another loop of water, ordinary light water, is allowed to boil and generate the steam needed to generate electricity. So in the Canadian system we have a pressured heavy water reactor.

Now, what's the significance of the heavy water. This is again quite technical, but it turns out it was discovered long ago, way back in 1939, it was discovered that when you're using natural uranium, uranium that just comes out of the ground without going through any fancy processing other than enriching - other than refining it, you can't get a chain reaction going unless you slow down the neutrons for technical reasons. So this slowing down process is called a moderator.

Now, if you're only using natural uranium it turns out that the only moderators that really work are either very pure graphite, which is what Chernobyl used, or heavy water which is this unusual heavy form of water where the hydrogen atoms are twice as heavy as usual, they're called deuterium atoms. As a matter of fact the CANDU acronym stands for Canadian deuterium uranium reactors, so CANDU is Canadian deuterium uranium. Now, the use of heavy water means that we can use natural uranium. So we have no enrichment facilities in Canada, nor do we need it. We don't have to buy enriched uranium because we can use natural uranium as our fuel. But heavy water is very expensive but the trade-off is that we don't have to enrich the uranium.

Now, for safety reasons this doesn't make a great deal of difference. What does make the difference is the fact that we use these pressure tubes, that's what makes the difference, and the fact that we have this pressure tube design - you see, here's the difficulty, is that in a - hello.

COMMISSIONER: We just have a small problem, Dr Edwards.

DR EDWARDS: I can't see you. Can you see me?

COMMISSIONER: No, we can hear you.

DR EDWARDS: Hello again. I got interrupted there.

COMMISSIONER: We're still - we can hear you but we can't see you hear.

DR EDWARDS: You can't see me. Okay, I have got my camera turned on, so I don't know why you can't see me. How is that? Well, actually I can talk without being seen. I can be like the Ghost of Christmas Past.

COMMISSIONER: Why don't we - we'll continue to try and connect you, but let's continue with the evidence.

DR EDWARDS: Yes. Fine. So it's this pressure tube design. You see the difficulty is with a CANDU reactor, with an American reactor they enrich the fuel so that they can use ordinary light water, just ordinary like tap water, you might say, only very pure, whereas in the CANDU reactor we use natural uranium so we have to therefore use heavy water as a moderator. With the CANDU design, when you lose the coolant, you do not lose the moderator, and that means that the reaction not only continues, but actually speeds up and so you get a power spike at the very moment that you have a loss of coolant, which is like a double whammy, it's like the worst of both possible worlds.

So this requires extra fast shutdown systems and that leads to the need for the duplication. Other than that, there's no real substantial safety difference, in my view, between CANDU and American light water reactors. Of course there are differences, but how significant those differences are is a matter of debate.

MR DOYLE: Dr Edwards, have there been any advancement in the specific means of ensuring moderation in a shutdown scenario?

DR EDWARDS: I'm sorry, I don't quite understand moderation - not moderation perhaps, but cooling, is that what you mean?

MR DOYLE: Yes.

DR EDWARDS: Cooling. Fortunately in Canada we have not had any meltdowns - well, not in a power reactor. We did have one of the world's first major nuclear accidents in 1952 involving a small research reactor called the NRX reactor which is a precursor of the CANDU and it involved a power excursion which actually destroyed the core of the reactor and blew the roof off. In a certain sense you could say it was almost like a very miniature, very, very tiny miniature version of a Chernobyl accident and that is, of course, something that gave the CANDU designers a great deal to think about when they were designing the upscale commercial sized power reactors.

But other than that, we have been very fortunate in Canada. We haven't had those types of accidents. We did have a Royal Commission inquiry in 1978, they published a report, this is the Ontario Royal Commission of Inquiry on electric power planning and they pointed out that under the most pessimistic assumptions that if we had 100 CANDU reactors operating in Canada, then again I stress under the most pessimistic assumptions, we could have a core meltdown about once in every - I believe they said four years or something like that, I may be wrong about the number, but they did say that you would be able to have meltdowns in CANDU reactors if you had a large enough number of them.

So far we have only got about 20 CANDU reactors in Canada and the population is not - that four years is wrong. I'm sorry, I misquoted that. I retract that evidence. It wasn't four years. I think it was once in 40 years. That's it, once in 40 years. That if we had 100 reactors operating in Canada at some future time, under the worst assumptions we could possibly have a meltdown once every 40 years. That's assuming, of course, that the technology remains unchanged and there aren't improvements made, et cetera, et cetera. So that puts it into a little more sobering perspective.

The difficulty with these reactor accidents is that you can't really say that for any reactor that such an accident is impossible. By its very nature it is possible, but it's highly unlikely. The difficulty with likelihood, and I'm a mathematics professor myself, the difficulty with probability is that it doesn't tell you, doesn't give you any assurance that something is not going to happen, it just tells you with what frequency you can expect it to happen, and it does not give you any way of predicting what's going to happen in a particular case. So that's why we always have to be constantly on guard and vigilant in dealing with these systems.

MR DOYLE: Dr Edwards, at that point it might convenient to move topics away from some of the inherent risks in the design considerations to the cultural and regulatory factors which in your opinion either detract from or assist in improving safety, and I wonder whether you might start with some observation about any of the particular inherent difficulties that arise in the nuclear industry because of its complexity.

DR EDWARDS: The complexity of the technology means that a lot of people are mystified by it, including decision-makers, and politicians, for example, generally don't necessarily have a background in nuclear science. One of the only ones I know, I think, was Jimmy Carter, he was actually a nuclear engineer in the American nuclear navy. But outside of him, I don't think of any major politician who has a background in nuclear science. So that the technology is sufficiently complicated that people tend to be mystified by it and therefore feel a little bit – they find it difficult to judge, other than by trusting the experts in the industry itself. The difficulty with trusting the people in the industry itself, is that there is either consciously or unconsciously a kind of a conflict of interest there because they are devoted to the industry and they want the industry to succeed and of course they try to reassure the public that it's safe and they try their best to make it safe but there is this problem of – well, what if they weren't so devoted to the industry and had the same knowledge, would they make the same judgment? Would they perhaps see it as being unsafe? And one of the difficulties with dangerous technologies is that people who work on the technology feel conflicted and it's difficult to blow the whistle on a technology that you truly believe in. So this is an inherent problem.

Similarly when you have a regulator, although independence is the goal, it's difficult to maintain that independence. The people in the regulatory body are often drawn from the very industry that they are regulating because they are experienced in that field and consequently you need people with understanding and expertise, so how do you kind of keep regulatory independent when in fact there is this constant interaction between the people in the regulatory body and the people in the industry. They tend to come to see themselves as colleagues and if I might draw an analogy, you might think of the regulator as drifting towards being more of a coach than a referee. We are very fond of hockey here in Canada and of course the coach of the team will try and keep the players on their metal and make sure that they're doing everything properly but it's not the same thing as a referee who will blow the whistle and say, go to the penalty box, right. So this problem of independence is not an easy one to deal with.

MR DOYLE: And what are the best ways of, from a regulatory point of view, of trying to encourage that independence? Are there any particular views you have about the way in which the regulator either reports to the executive or parliament, or through different ministers that assist in preserving that independence?

DR EDWARDS: I think it's very helpful to have frequent – well, we don't have this in Canada but I think that the regulator should probably report annually to the parliamentarians so the parliamentarians can hear what kind of concerns are crossing the desk of the regulator and get some kind of insight in to the technology. Have an opportunity to ask questions and to learn more about it. There is a danger that if the regulator never interacts with the decision makers, or the parliamentarians that it just creates a widening gap, rather than an (indistinct) Another thing that I think would be very helpful in my own opinion would be regulators, as the industry itself, they tend to be very top heavy with engineers and physical scientists, geologists and such like, chemists, the so-called hard scientists and they tend to be extremely thin on biomedical expertise. I think it's very helpful to have some biomedical expertise in the regulatory body because they have a different perspective. They have a different approach and also if and when things do go wrong, the biomedical team can be very helpful in advising the public and the workers and everybody, as to what kind of precautions to take in terms of protecting yourself. What kind of foods should be avoided? What kind of measures should be taken? I think it would be very reassuring to the public to have such people on board.

Moreover, if you had a health department, which we do not have in our regulator, if you had a health department staffed with competent and independent biomedical people, they could also help to educate workers and the public as to why we are so careful with this technology. Why we must invest in all these safety precautions because they could make it clear what the dangers are. And they could also make it clear, such basic things as informing people that if and when God forbid that there should be an accident or release of radioactivity, don't think of it as a problem of invisible rays coming from the plant, but realise that it's a problem of a multitude of pollutants going out in to the atmosphere and settling in to the food chain, so that the important thing here is not to think so much in terms of the penetrating radiation, which is the immediate risk to the workers, but to think more of the food chain and what kind of foods – for example, just to give a very simple example, it's well known that iodine 131 goes to the thyroid gland very avidly and especially in very young children can cause thyroid cancer and a multitude of other diseases.

This is why, for example, in Canada, we now distribute iodine tablets, non-radioactive iodine tablets to everybody within a certain radius of a nuclear facility, so that – the reason for these iodine tablets is that by taking the iodine tablets you can put non-radioactive iodine in to your thyroid gland which means that your body will then reject the radioactive iodine because it's already saturated. It's already got enough iodine, it doesn't want any more. So that it's a preventative measure. Now this is very important for young children, so that for example it would be beneficial to have health professionals who could tell nursing mothers and parents of young infants, perhaps for the time being to stop using fresh milk and start using powdered milk. Powdered milk that was stored before the accident occurred and this way you can cut off that milk source is one of the main ways by which the radioactive iodine gets in to the bodies of young children and nursing mothers as well.

MR DOYLE: You have been addressing the topic of making sure that there's a proper engagement with the community about the nature of the danger presented by a potential nuclear accident. I wonder if there's also a need to ensure that there's enough transparency at a regulator and operator level to ensure that the public has an appropriate level of comfort in relation to preparedness for external events and so forth.

DR EDWARDS: Well, that is something that one has to be very careful with. In the case of nuclear technology, as opposed to the safety questions which is what we've been talking about here, there are the security questions. Now security is different from safety. Security means protecting against malicious acts, for example somebody who might want to steal radioactive material for malicious purposes, so-called dirty bomb or some kind of malicious contamination. Security is very important, not only with the theft of radioactive materials, particularly plutonium which can be used for nuclear weapons and which every nuclear reactor does produce, but also in this world, unfortunately we have to worry about such things, terrorist attacks. We've seen the planes that brought down the World Tower in New York City. We certainly don't want to see that happening at a nuclear reactor. So one does have to have extraordinary security measures in place. And in fact here in Ontario at the Bruce power plant we have a SWAT team which is very, very well trained and they have participated in competitions and have won prizes for being extremely effective at stopping any kind of intruders. So these are things that have to be thought about in the case of nuclear technology which don't readily arise in most other circumstances.

COMMISSIONER: Dr Edwards, we still can't see you but I do thank you for your evidence this morning and I wish you the best for the future.

DR EDWARDS: Well, thank you very much and the same goes to you and I – one day I hope to find myself in Australia. I've never been there but I'm looking forward to coming some day.

COMMISSIONER: Thanks Dr Edwards.

MR DOYLE: Thank you.

DR EDWARDS: Thank you.

COMMISSIONER: We will now adjourn until 12.30 when we will have Professor Peterson.

ADJOURNED **[9.48 am]**