Interview with Dr. George Apostolakis, Director of Nuclear Risk Research Center, Central Research Institute of Electric Power Industry

# Building Trust in Nuclear Power Stations Needs Knowledge Sharing Process

By *Japan SPOTLIGHT*

**Nuclear power is still an important energy source, as well as a renewable energy at a time when promoting clean energy to realize a zero-carbon emission economy is becoming crucial. But the most important question is how to ensure the safety of nuclear power stations. One quantitative analysis method called Probabilistic Risk Assessment (PRA) is highlighted here, as it could help to achieve it. This can be regarded as another example of Evidence-Based Policy Making (EBPM).**

***Japan SPOTLIGHT*** **held the following interview with Dr. George Apostolakis, a distinguished nuclear engineering expert and director of the Nuclear Risk Research Center (NRRC) of the Central Research Institute of Electric Power Industry (CRIEPI) in Japan.**

**(Interviewed on Feb. 8, 2022)**

## Introduction

**JS: Could you briefly tell us about your professional and academic background?**

*Dr. George Apostolakis*

**Apostolakis:** I did my undergraduate degree in Athens in electrical engineering, then went to Caltech in Pasadena, California, where I got my Ph.D. in 1973. Then I joined UCLA as an assistant professor (eventually promoted to professor) until 1995, when I moved to MIT in Boston. In 2010, I was nominated by President Barack Obama and confirmed by the US Senate to the Nuclear Regulatory Commission in Washington, so I moved there and stayed for four years. Then, in 2015, we moved back to Los Angeles where we have family.

My area of specialization is Probabilistic Risk Assessment (PRA). We started as a community designing nuclear reactors in the 1950s, 1960s and 1970s. The approach to design and safety was what I call bottom-up. In other words, you look at the various components and systems and you have requirements for valves and pumps and so on, and we design them according to those requirements. Then, we assume that the plant is safe. A different approach is a top-down. You look at the plant, as a system consisting of hardware and humans, and you ask yourself what can go wrong? There are three questions that define PRA.

What could go wrong – which means developing accident scenarios. What are the consequences of each scenario? Is it damage to the reactor core, is it a release of radioactivity, is it public health, and so on. And the last question is, how likely are these scenarios? So you have thousands of accident sequences, and you assign frequency to each one, and according to the frequency you can prioritize. Instead of looking at thousands of sequences, it turns out that for public health effects, it's usually about 15 sequences that matter, i.e., they are most likely. From thousands to 15, so that's a major advance. The other difference between the top-down and the bottom-up approach is that the top-down approach – which looks at the plant as a system – recognizes that there are human operators who will intervene in case something goes wrong. The possibility of human actions is included in the development of accident sequences. This is a very important point because up until the early 1970s the nuclear community did not pay much attention to human error. It was the first PRA – which was called the reactor safety study published in 1974 – that showed that human performance is important, which of course makes sense.

So that is what PRA is. It looks at the reactor and the plant as one system, and asks the three questions: What can go wrong? What are the consequences? And how likely is it? It's both quantitative and qualitative analysis.

## How PRA Works

**JS: Could you provide an example of this assessment**

**that might enable us to understand exactly how it works?**

**Apostolakis:** Suppose that the reactor is operating under normal conditions producing electric power. Then, for some reason, there is a fire in one compartment at the plant. This is an abnormal situation. The control room is notified and now we start developing possible accident sequences. The first thing that the plant people will try to do will be to isolate the fire and stop it from spreading. Maybe the fire brigade will go. So now we start developing possibilities. Is the fire extinguished within a short amount of time and if it is, what is the damage? The other possibility is that the fire is not extinguished, and it damages some equipment in that compartment. That now creates a new group of accident sequences because now you have the fire, you know which components are damaged, and what happens next. If it propagates to another compartment, you have additional possibilities that the fire will damage additional equipment and so on. So you see how you generate many accident sequences simply by the initiator of a fire. That is what we do, and we have a computer to help us, and we end up with thousands of sequences.

**JS: How do you assume probability for each consequence?**

**Apostolakis:** Each accident sequence starts with what we call an initiating event. The example I gave you is a fire at a particular place. Another example is an earthquake, a human error, and so on. The initiating event frequencies typically are produced by statistical evidence. We have had several thousand reactor years in operation worldwide, so we have an idea how likely these events are. In some cases, we have to do more analytical work because statistical evidence is not sufficient. You have the frequency of the initiator; then we develop probabilities for damage. As I said, a fire may damage a particular component. The question is now, what is the probability that given this fire, the component will be damaged. And there is evidence, experimental, statistical, expert opinion – and we put all these together and come up with a probability of damage. We do this where it is required, and it is a combination of statistical evidence, engineering knowledge, testing and expert opinion.

**JS: To be as objective as possible on this assessment, do you need lots of big data?**

**Apostolakis:** Not really. The issue of how objective a PRA is, is a very important one. We have approached this in several ways. The international community has developed standards that when someone in Japan or in Sweden wants to do a PRA, they follow these standards. But even if you follow the standards, there is a lot of utilization of expert opinion which is subjective. So, the second method for ensuring objectivity is to have peer review. You put together a group of experienced PRA experts and engineers who have nothing to do with the original PRA, and they spend serious amounts of time reviewing the PRA at hand. They make numerous comments that the original team must respond to. These are the two main ways that we are using to ensure objectivity in the PRA.

**JS: You have clearly outlined how PRA works for safety in nuclear power stations. Is this PRA method applied in other areas?**

**Apostolakis:** It has been applied in space shuttles, and I know that the coast guard in the United States has also used it, as well as some chemical facilities. The extent to which they are using it varies from industry to industry; the nuclear power industry is more rigorous because of the regulations. Other industries are not as heavily regulated as nuclear power.

**JS: Would you say that PRA is limited to certain areas in which the risk is considered very important?**

**Apostolakis:** If you don't have significant potential risk, there is no reason to do a PRA. You can do some PRA that is a little shallow, not as detailed as that for nuclear reactors.

## What PRA Has Achieved So Far

**JS: How is the information obtained from PRA to be used for specific risk management in a nuclear power station? Do you think so far that a nuclear power station's safety has been enhanced by PRA?**

**Apostolakis:** Yes, there have been several studies that I am aware of in the US. One of the metrics that we use is frequency of core damage. This is a very important metric – the frequency per year of damage in the core. If you look at the plot of the core damage frequency as a function of years going back to 1970 up until today, there is a very clear picture of the curve going down. The core damage frequency is improving over the years. This is to a large extent due to the utilization of PRA.

**JS: Does the IAEA consider PRA as an important analytical tool for ensuring the safety of nuclear power stations?**

**Apostolakis:** Yes, they have issued safety guides and other documents where they promote the utilization of PRA.

**JS: The IAEA set up its own safety standards for nuclear power stations. PRA is a very important component to encourage people to observe these standards.**

**Apostolakis:** The standards in each country more or less comply with those of the IAEA.

**JS: Do all nuclear power stations have to apply PRA today?**

**Apostolakis:** Yes, it complements the traditional safety principles. We have tools that look at the plant as a whole. We are not eliminating the traditional requirements on systems and components; by and large they are still in force. It is just a different way of looking at the plant.

**JS: Is it costly for companies to apply PRA?**

**Apostolakis:** Yes, it is costly. But it is a very ambitious undertaking because it models the plant no matter what happens – a fire, an earthquake and so on. So it is really an ambitious undertaking and requires many different types of expertise which means it becomes expensive. You need systems people who understand how the plant works; you may need seismic experts, fire experts, human performance experts. In fact, this is one of the strengths of PRA – it brings together such diverse disciplines. I remember when we started paying serious attention to human error, we had meetings of engineers and psychologists. Psychologists were never part of designing nuclear power plants, and here we had them advising us on human performance. This is one of the great strengths. The other thing that makes it expensive is the peer review that I mentioned. This can also be extensive and expensive because you have to pay the experts, the reviewers, and these are usually experienced people who are expensive.

**JS: Related to your explanation on how PRA works for nuclear plants, in terms of thinking about possible events initiating accidents, how do you define the risk and how do you allocate probability to each risk?**

**Apostolakis:** As I mentioned, the list that is widely used now – there is one for pressurized water reactors and one for boiling water reactors – comes from experience, international experience. You have reactors operating in the US, Japan, Sweden, and Taiwan and there are international organizations that keep track of the evidence. So, for example, in the early days, people thought that the most severe possible accident is the guillotine break of the largest pipe with water in the plant, a so-called large loss of coolant accident. We have never seen it. The statistical evidence says that this is an extremely unlikely event. All over the world we have never seen a major coolant accident. So you have the statistical evidence and the expert opinion, and we try to combine the two. We cover all the risks including all the unexpected ones.

**JS: Could you please give us your overview on some OECD nations' application of PRA such as the US, the United Kingdom or France? Do you think PRA has been widely used in the world?**

**Apostolakis:** Yes, it has. It depends on the culture and the political system of the country. In the US, we tend to be very legalistic, so we develop rules, the authorities get involved, and the documents spell out clearly what you are supposed to do and so on. In other countries, my experience is that they are not so formal. The French, the British, the Swedes, the Finns, Taiwanese, South Koreans have all used PRA. But the utilization is not as public as it is in the US. That doesn't mean they are not doing a good job; it is just that they don't put it out in the public for everyone to see. In Japan, with the NRRC and especially after the Fukushima accident, we are trying to be as open as we can. We are publishing everything we do on our website; we have our own advisory committee that reviews our work. They write letters to us and sometimes are critical. We publish those letters too, as well as our answers. So we are trying to bring more openness in the system, at least when it comes to PRA because we must gain the trust of the public. If the public suspects that you are not completely open with them, then trust disappears.

**JS: In Japan, you mentioned that PRA has been applied to nuclear plants. Could you explain a little about the history of PRA in Japan? Was it introduced a long time ago or more recently applied?**

**Apostolakis:** It was used to some degree before Fukushima. But I must say, the results of PRA were not really taken so seriously, and the system was still deterministic – a bottom-up approach. This meant that there was a tendency to produce very low probabilities for accidents. Peer review was almost non-existent. Now that we are trying to build up trust, we have asked the PRAs of two model units – Kashiwazaki Kariwa and Ikata – to be reviewed by international experts. So we implemented the PRA requirement of the international community. These reviews worked very well. The experts made many substantial comments, and the utilities responded by modifying their PRAs. The understanding was that the other utilities would follow what was happening at Kashiwazaki Kariwa and Ikata, and upgrade their own PRA. So this was one of the most important elements in this area in Japan.

At the same time, as Japan is vulnerable to severe natural events, we are developing probabilistic methods for severe earthquakes and tsunamis and the combinations of both, because in other countries some of these natural events have been analyzed in detail, such as earthquakes, while others such as tsunamis are unique to Japan. So, we are developing the tools that the utilities can use to quantify the sequences for earthquakes, tsunamis, tornadoes, volcanoes – hazards that are really important for Japan.

## Restoring Trust in Nuclear Power Stations by PRA

**JS: Building up trust is very important in the case of the utilization of nuclear power. In your assessment so far, has PRA worked well in building up trust in Japan?**

**Apostolakis:** No. First of all, when you talk about trust, you have to consider the general public and also the expert community. I think PRA has made progress among the technical community. There is still some reluctance on the part of the regulators to use PRA in regulating but we are making progress. The Nuclear Regulation Authority (NRA) is now using the reactor oversight process that utilizes risk insights. This is the oversight process that we use in the US. When it comes to the general public though, this is perhaps too much of a technical issue. I don't think people are impressed, and so I am not sure we are making significant progress in that regard. As many people have said, trust is easy to lose but gaining it back is really very difficult. But I think the openness that I mentioned early is one element. We publish everything on our website and people can see what we are doing right and what we are doing wrong.

**JS: I think nuclear power would be an important energy source for Japan in achieving zero carbon emissions. To take full advantage of nuclear power to achieve a green economy, PRA would be important evidence encouraging safe utilization of nuclear power. You mentioned that openness is very important in achieving progress, but how about other aspects? For example, communication skills to convince ordinary people of the safety of nuclear power plants. How can we improve communication with the general public on PRA?**

**Apostolakis:** This is the million-dollar question that nobody knows the answer to. We have a risk communication group in the center, and they are doing their fair share, but in the US I don't think that the average person really cares about the quantitative analysis that something is safe. So, I don't think anybody knows the answer; it takes a long time to build trust, and when something happens as an industry, we have to be very open and not to cover up even minor incidents. It's really a very slow process. I don't think that trying to educate the general public on PRA is particularly meaningful. So let's start with the experts, the regulators, and the industry.

**JS: Scientists seem to play an important role in explaining very complicated events to the general public.**

**Apostolakis:** If it works, fine with me. I don't know of anybody who can do that. I am sure you are aware, this was a really big accident. Fukushima was not just a minor thing, and it really shook up the public's trust in the industry and the government, and the regulatory agency. So it will take a long time. Already I believe that 10 units have restarted. If you look at it after such a major incident, we have 10 reactors that have restarted 10 to 12 years later; that is probably a good sign.

**JS: Not limited to the case of nuclear power, should people become more accustomed to quantitative analysis?**

**Apostolakis:** Yes, absolutely. The attitude of the public or members of the public is a mystery sometimes. Look at the reaction against vaccinations all over the world. I can't believe that people go down and demonstrate against the vaccines which quantitatively have proven they can help you against Covid-19, yet you have demonstrations in Paris, Washington, Brussels and so on. Who are these people? Communicating with the public on technical matters is really an unsolved problem in my opinion.

**JS: We need a long-term solution and improving science education could be a solution in the long run to help people understand what quantitative analysis is. Today, science, life and business are closely related to each other.**

**Apostolakis:** Absolutely. JS

Written with the cooperation of Joel Challender who is a translator, interpreter, researcher and writer specializing in Japanese disaster preparedness.