Fukushima in Retrospect

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Editor's comments

Although the following paper was written over two years ago, the controversy over the future energy supply continues to rage on around the world. The major universal contenders appear to be nuclear power plants on the one hand and gas, oil, and coal burning plants on the other. There are other sources of course, but due to high cost or lack of reliability when needed, these other sources may be considered as relatively minor contributors for the foreseeable future.

True that all have their risks of different kinds, whether to safety, health or damage to the environment. However, the population at large is in no hurry to avoid these risks by giving up their cars and living in the dark. The fact is that with an increasing population demanding an increase in energy to satisfy today's technology driven world, sound sources of energy are essential. Without it, economies will collapse with all the hardships and conflict that this implies. One does not have to look far to see evidence of this around the world.

These issues are not just questions of academic, political, environmental or even engineering interest. They are of serious concern to the project management community at large because large investments are involved with consequent project management work. However, the risk tradeoffs, or public perception of risk, will eventually determine the source of large numbers of positions for project managers and their support consultants. That is, in which part of the energy industry these positions will occur.

The next generation of project managers will certainly be anxious to decide in which direction to focus their careers.

Fukushima – by Bill McAuley and Robin Grimes

The welcome absence of international press attention has permitted the Japanese authorities and the International Atomic Energy Agency (IAEA) to return to their work in relative peace and quiet. The following paper and comments, compiled by managing editor Bill McAuley with the help of Robin Grimes (director of Imperial's Centre for Nuclear Engineering), reviews the Japanese nuclear power failure event and its long-term impact on the continuing development of nuclear energy. They also summarize the way Imperial continues to contribute to the debate and the cross discipline research that is taking place.

As professor of Materials Physics and director of the Centre for Nuclear Engineering, Robin Grimes (pictured) is a driving force behind Imperial's courses in Nuclear Engineering, in addition to his research responsibilities. He is also currently specialist advisor to the UK House of Lords' science and technology select committee while they deliberate what nuclear research is needed through to 2050.

The Centre for Nuclear Engineering brings together a number of disciplines including Mechanical, Chemical and Materials engineering, but also specialist modeling and radio ecology people, to create one of the most comprehensive research and teaching groups in Europe dedicated to nuclear engineering and science. Greater cross-disciplinary awareness of the research interests and capabilities of Centre members encourages collaboration and supports joint teaching activities.

Imperial College has a long history of nuclear research and teaching, dating back to the immediate post-war period. However, the present undergraduate nuclear engineering courses were started five years ago and now graduate between 20 and 30 students a year. There is also a new MSc in Nuclear Engineering that graduated students for the first time in 2010.

The Earthquake and its immediate aftermath

On the afternoon of Friday, March 11, 2011, an earthquake of Richter magnitude 9 occurred with its epicenter off the northeast coast of the Japanese island of Honshu. The Japanese infrastructure withstood the earthquake well but was devastated by the tsunami that followed, with unprecedented loss of life and property.

The Fukushima I nuclear complex is owned and operated by Tokyo Electric Power Company (TEPCO) and consists of six boiling water reactors (BWR5) of General Electric Company (GE) design. The first reactor was commissioned in 1971. At the time the event took place, units 1, 2 and 3 were operating and units 4, 5 and 6 were shut down for periodic inspection. Units 1, 2 and 3 started the process of automatic shutdown (SCRAM) when the earthquake struck.

None of the reactor containment vessels was compromised despite the earthquake's magnitude being considerably greater than the maximum design specifications for the reactors. The tsunami arrived 50 minutes later and, at a height of 13m, overwhelmed the 5.7m sea wall. The diesel generators providing emergency power were flooded and put out of action, leaving the cooling water pumps dependent upon batteries. The pumps shut down after depletion of the batteries.

This loss of cooling water led to partial meltdowns in reactors 1, 2 and 3 in the hours and days following the accident. The inability to control temperatures also caused the metallic cladding, which contains the uranium dioxide fuel, to react with the residual water and evolve hydrogen. This was released from the reactor pressure vessels and collected in the roof space above the reactors. It detonated on March 12, 14 and 15. Unit 4 also suffered explosive roof damage on March 15.

It is now thought that the hydrogen source was unit 3 rather than a source in unit 4. The situation was stabilized over several weeks using a series of ad hoc measures, including seawater flooding.

The complex of four reactors at Fukushima II is situated 7.5 kilometers from Fukushima I. It too experienced cooling water systems failures but achieved cold shutdown by March 15.

Present status

At the time of this writing, reactors 4, 5 and 6 are in cold shutdown (sustained temperatures below 100^0C). Reactor 4 is defueled. Reactors 1, 2 and 3 are targeted to be in cold shutdown by the end of the year and the nuclear world will be closely monitoring progress towards this goal.

Internationally supported efforts continue to cool the reactor cores and to decontaminate the very large quantities of sea and fresh water used for emergency cooling in the early stages of the accident. Total cleanup will take at least 10 years according to TEPCO and up to 30 years in the opinion of others. TEPCO has announced that reactors 1-4 will be scrapped. The fate of 5 and 6 is uncertain, as is that of Fukushima II. The 20km exclusion zone remains, although a few intrepid souls have returned.

In the wake of the earthquake, tsunami and accident, over half of Japan's 54 reactors are not currently operating, resulting in extreme pressures on the country's electric grid. The debate has been reopened on the future of nuclear power, both within Japan and in the wider world.

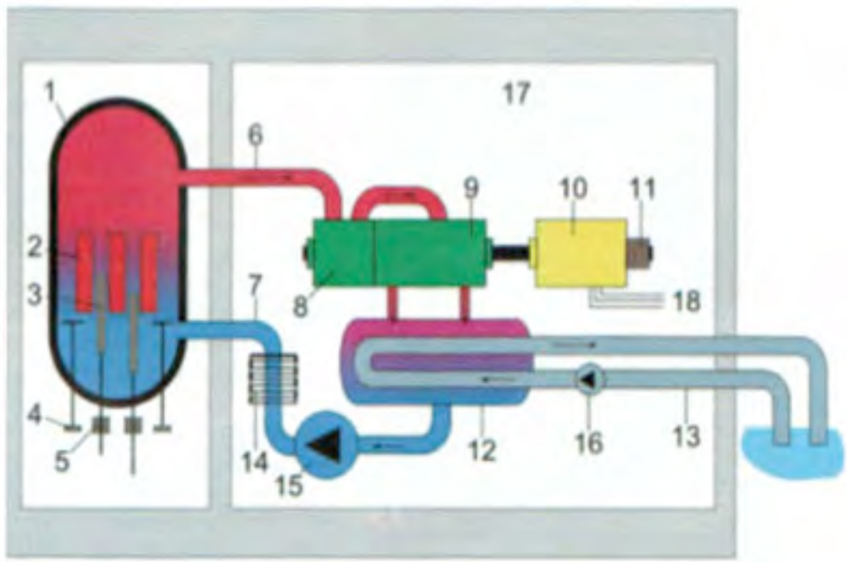

Figure 1: Simplified diagram of a boiling water reactor.

Key to diagram: 1. Reactor vessel, 2. Fuel core element, 3. Control rod element, 4. Circulation pumps, 5. Control rod motors, 6. Steam, 7. Inlet water circulation, 8. High-pressure turbine 9. Low-pressure turbine, 10 & 11. Electrical generator, 12. Steam condenser, 13. Cold water for condenser, 14. Pre warmer, 15. Water circulation pump, 16. Condenser cold water pump, 17. Concrete chamber, 18. Connection to electricity grid.

Root causes

It would be very presumptuous of this paper to pronounce too far on this topic but some general comments can be made. In spite of their age, the reactors survived an earthquake of unprecedented magnitude. However, the cooling systems did fail and the plans to deal with this eventuality were not adequate, as evidenced by the ad hoc nature of the initial response.

An obvious deficiency was the installation of the emergency pumping equipment at ground level. Since the probable consequence of an offshore earthquake would be a major tsunami, it is inconsistent to design reactors to survive severe seismic events but not carry this thinking through to the auxiliary systems. There is, however, a more subtle factor at work. During the last several decades, the international climate of antipathy towards new generation plants has encouraged extending the life of existing facilities. At the same time, cost pressures have tended to discourage capital improvements at these facilities.

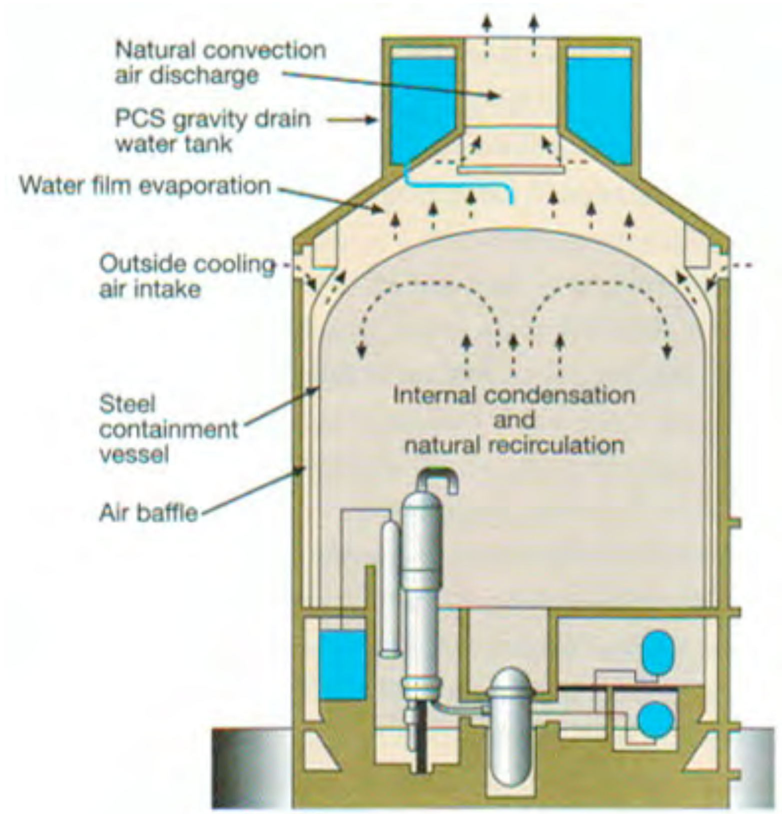

Figure 2: Westinghouse's passive containment cooling system.

Then and now

The basic design of Fukushima I dates from the late sixties. That is almost 45 years ago! A review of the improvements in other technologies since then makes one instantly realize how much the technology must have improved – but to many of the general public, nuclear power remains mysterious and menacing. With the exception of France, Korea, India and China, countries discontinued most of their nuclear power development programs from the late 70s.

The industry convention is to group reactors into Generations I, II. III and IV. Simply put, "I" represents the prototypes built until the mid 60s; "II" the plants built from then until the mid 90s (i.e. most plants in current operation) and "III" the "new versions" incorporating improved fuel technology, thermal efficiency, passive safety systems and standardized designs. Generation "IV" are design concepts and are therefore beyond the scope of this discussion.

The overriding issue is safety. In this context it is worth examining the four Westinghouse AP 1000 plants currently under construction in China. This Generation 111+ design employs a passive cooling system.

Crucially, external AC power is ***not*** required for maintenance of cooling in the type of emergency experienced at Fukushima or Three Mile Island. In addition, water cannot drain from the spent fuel pool even if water is lost. The design was approved by the Nuclear Regulatory Commission in 2005 and is currently under assessment by the UK office for nuclear regulation.

With the merciful absence of any serious long term threat to human health from the incident (so far!), governments should finally give the green light for replacement and expansion of our Generation II plants.

Health scare exaggerated
Says Don Higson (Chem Eng 57)

> "I would say the 'immediate threats to public health' from radiation at Fukushima are essentially zero (except for the mental health effects caused by removal of people from their homes and by unwarranted anxiety about radiation). Temporary evacuation was justified as a precaution, at potential dose levels well below levels that would be dangerous to physical health, but I do hope that the evacuation is not prolonged more than is absolutely necessary.
>
> I think the figure of 60 for the total fatalities in the Chernobyl incident is a bit high, if you mean near term fatalities attributable to radiation. I would put it at less than 50.There were, of course, another two who died immediately from other causes and one who disappeared, presumed dead. The figure of 20 deaths, referred to in my paper as having 'since died from illnesses that are considered to have been associated with acute exposure' actually includes a number of cases where radiation was really not a likely cause (e.g. when I last looked, it included someone killed in a car accident). Deaths from thyroid cancer came years later.
>
> I doubt that the number of thyroid cancer deaths that were probably caused by radiation will ever reach 500, but we will never know. I expect there will eventually be about 2,000 identifiable cases of thyroid cancer more likely to have been caused by radiation from Chernobyl than anything else, and that these cases would eventually lead to around 100 deaths. Some people might call this 'a major public health impact'.
>
> There will also he statistical predictions of increased incidences of other cancer deaths but these increases will not he significant compared with normal. Essentially, they will be speculative. No individual case (apart from thyroid cancers discussed above) will be identifiable as having been caused by the Chernobyl accident."

Subsequent to the preparation of this web site paper, Don Higson sent us this Email on 02-19-2013:

> "Hi Folks
>
> In the report to the UN General Assembly of its 59th Session (21-25 May 2012), the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) confirmed that there have been no health effects attributed to radiation exposure observed among children or any other member of the population at Fukushima.
>
> UNSCEAR has also withdrawn its previous support for the assumption of a linear relationship between dose and risk (the LNT model). The Committee now recommends against the application of this assumption for estimating risks from doses ***'that are typical of the global average background levels***'.
>
> ***No member of the public*** at Fukushima ***was exposed to radiation at a rate outside the range of variation of natural background radiation around the world***. Hence, no public health effects attributable to radiation exposure should be expected.
>
> Although about 170 occupationally exposed people are reported to have received doses

from which there is a small risk of future health effects, no health effects attributed to radiation exposure have been observed.

Best regards, Don Higson"

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We need nuclear
Says Ashley Callerall (Materials 52)

"The over riding responsibility of any government in the energy scene is to ensure security of supply of fuel and power to its community. This requirement takes precedence over all other considerations, including climate change. The social and economic consequences of a failure to do so are immediate, severe and widespread. As a result it has to take account of the political and technical situations existing at the prime sources overseas, particularly of oil and gas, which may he unstable and outside the control of the government.

To maximize security, therefore, it is prudent to have a mix of sources including coal, oil, gas, nuclear and renewables, so that if oil and gas supplies are interrupted, the wind doesn't blow, or the sun doesn't shine, some energy is available to the system.

The exceptionally severe tsunami in Japan, of magnitude 9 or so on the Richter scale, caused between 15,000 and 20,000 deaths according to reports, but media coverage has concentrated almost entirely on the incident surrounding the nuclear station at Fukushima. So far this has caused no deaths.

The reactor designs of Fukushima, the oldest nuclear station in Japan, were of 1960's vintage, and a long way from current designs. Moreover, there are around 50 nuclear power plants on some 17 sites in Japan, which were unaffected by the tsunami.

So let us keep a sense of proportion. The nuclear industry has a good safety record and does not deserve the vilification it receives. We need it."

jacatterall@btinternet.com

1000 deaths

In a parallel discussion within the Canadian Society of Senior Engineers (CSSE), Dan Meneley of the Greater Ottawa Chapter, wrote in CSSE's October 2012 News Letter:

"The third disaster, still unfolding, arose from reactions to an unjustified but intense fear of ionizing radiation. This fear led government authorities to force large numbers of people to remain far away from their homes for no sound reason. This was and is a fake disaster."

To which we inquired of the newsletter's editor:

"So what evidence is there to support Dan's assertion that the government's actions were 'for no sound reason'?"

Dan Meneley was good enough to respond directly, in part, as follows:

"Radiation protection law in Japan (and largely around the world) is based on nearly century-old data that have been discarded and replaced by more accurate knowledge. Unfortunately, the updated facts have not been applied to bring laws up to date. This, plus widespread fear of ionizing radiation, has led to a situation in which the laws designed to protect citizens sometimes put them at unnecessary risk."

"Putting oneself in the decision chair in Tokyo, I myself would have been inclined to evacuate ASAP and then work out the details. My options would have been dictated to a large extent by Japanese law. So, the term 'unnecessary evacuations' is only partly correct. YES – from the scientific point of view, almost all of the evacuations were unnecessary. From the point of view of common sense, it made no sense at all to try to prevent a few deaths in the midst of the [tsunami] holocaust-by-drowning on that coast of Japan at the time. But NO – these evacuations were mandated by the existence of a long-standing law based on fallacious reasoning, and not the only such law in existence, I suspect.

Undoing a bad law requires a good deal of time, patience and understanding. The scientists are saying that the law is wrong; perhaps over the next 50 years or so, essentially all humans still living will agree on this point. But the official who ordered the evacuations was not in a position to save those thousand or more lost lives, on that particular day.

[But] surely one must try to set things right? I've been trying, in my amateur way, to get this done for about 25 years. One big problem is that scientists and engineers have only tiny voices in this multi-lawyered world.

In short: Because Japanese radiation protection law at the time was unduly strict, a large number of Japanese citizens were evacuated after the Earthquake/Tsunami event at Fukushima, and were not allowed to return to their homes in a timely manner. Japanese authorities have concluded that the lives of more than one thousand people were lost as a direct result of this erroneous law."

Editor's post script

According to ***Nuclear Power in the World Today:***[1]

- The first commercial nuclear power stations started operation in the 1950s.
- There are now over 430 commercial nuclear power reactors operating in 31 countries, with 372,000 MWe of total capacity.
- They provide about 13.5% of the world's electricity as continuous, reliable base-load power, and their efficiency is increasing.
- 56 countries operate a total of about 240 research reactors and a further 180 nuclear reactors power some 150 ships and submarines.

Sixteen countries depend on nuclear power for at least a quarter of their electricity. France gets around three quarters of its power from nuclear energy, while Belgium, Bulgaria, Czech Republic, Hungary, Slovakia, South Korea, Sweden, Switzerland, Slovenia and Ukraine get one third or more. Japan and Finland normally get more than a quarter of their power from nuclear energy, while in the USA one fifth is from nuclear. Among countries that do not host nuclear power plants, Italy gets about 10% of its power from nuclear, and Denmark about 8%.

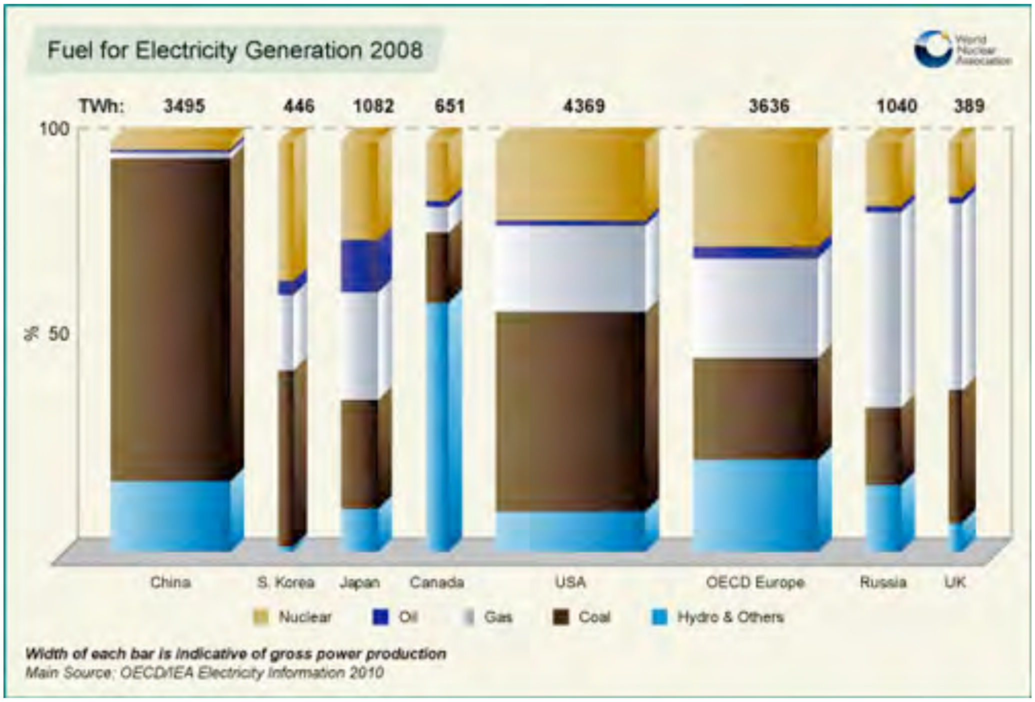

Figure 3: Distribution of fuel used for electricity generation in 2008

Coal is the largest source and undoubtedly the dirtiest of all.

Environmentalists please take note.

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[1] See http://www.world-nuclear.org/info/inf01.html