Fukushima: Consequences of Systemic Problems in Nuclear Plant Design

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The existing systemic uncertainty affecting nuclear power plant design the world over raises the question of whether society is willing to continue with a never-ending learning process, with potentially high adverse consequences – both to humans and to the environment. Developing new designs will not lead to improved nuclear safety but will simply maintain the technological lock-in put in place by the civilian nuclear industry.

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The unfolding tragedy at the Fukushima-Daiichi nuclear power plant has obviously raised concerns in parts of the world about nuclear energy, and whether or not it is an option in the discussion about alternative energy sources. I say "in parts of the world" because while in a few countries, such as Germany, radical decisions have been taken against nuclear power in the future energy mix, many others keep saying that nuclear power is safe despite the obviousness of the current events in Japan. Indeed, in the United States, the trend is to "stay the course" and for the government to reaffirm its intention to clear new plants. In France, officials say that there is "no way to phase out nuclear". This is the same situation of a status quo both in Spain and in the UK, while in Italy a referendum on nuclear power is scheduled for 2011. In India, it seems that the direction is to maintain the 9,900 MW Jaitapur nuclear power project being constructed by a French consortium led by nuclear reactor maker Areva.

To back up their positions, nuclear power proponents try to reassure public opinion about safety. There are two arguments that are made to reiterate the safety of nuclear power.

Argument #1: "The accidents at the Fukushima-Daiichi nuclear power plant are due to a unique occurrence of two natural disasters – an earthquake and a tsunami".

In media coverage, the Fukushima-Daiichi nuclear accidents have often been referenced to the "Japanese earthquake and tsunami disaster" (for example on the website of the International Atomic Energy Agency (IAEA).[1] The use of a certain semantics referring to *natural* disasters rather than to a *nuclear* disaster leads one to think that the Fukushima-Daiichi accidents are only due to the Tohoku earthquake and tsunami, with no responsibility shared by the nuclear industry. However, I argue here that the natural *events* play only a limited role in this nuclear *disaster*.

Nuclear energy is all about controlling an energy source with a very high density. As part of that control, many components are in place in order to always maintain such control and to avoid potential accidents. Those components are designed so that if one fails to work properly, another takes the relay. Redundancy and spatial separation are therefore used as a basis for plant design to always make sure that the functions are maintained. Some functions are more important for the overall safety of the plant than others, so their design is prioritised over others. For instance, the core cooling system is one of the most critical functions of a nuclear reactor and hence it must be maintained at all cost. As there is no "zero risk" with every design, all functions in a plant are based on "probabilistic risk assessment" (PRA). The PRA methods depend on three variables: (1) the magnitude (severity) of a possible adverse event; (2) the likelihood (probability) of its occurrence; and (3) its possible consequence(s). The overall safety of a nuclear power plant is therefore a tradeoff between certain assumptions about the severity and the likelihood of different adverse events. By definition, component failures are thus part of the design choices (giving priority to certain functions), but they can be kept to a minimum within the component-level probabilistic risk assessment.

Interdependent Events

Natural events are also taken into account – to some extent – in the plant's design as part of the PRA. In the case of the Fukushima-Daiichi nuclear disaster, two natural events happened: an earthquake and a tsunami. However, saying that the nuclear disaster is due to the accumulation of both an earthquake and a tsunami entails confusion as it leads to think that both natural events were not related. In fact, it is known from earth science that a mega-thrust earthquake occurring undersea can potentially provoke a tsunami. Indeed, the most recent example is the 2004 Indian ocean earthquake and tsunami, although in that case the earthquake was totally undersea (i e, no peak ground acceleration). Therefore, earthquakes and follow-up tsunamis are not independent events contrary to what was considered in the design of the plant. As a result, the Fukushima-Daiichi nuclear disaster is partly due to the fact that knowledge from earth science had not been understood enough at the time (or were not available) of the power plant design, rather than simply the fact that a *quasi-impossible* natural "disaster" actually happened.

In addition, the PRA methods used for taking into account some natural events can be criticised. Indeed, in the particular case of earthquakes for instance, there is a high uncertainty when performing the seismic hazardous analysis (e g, the maximal seismic magnitude which can occur in a certain zone of seismic activity) since it depends on earth science practices. This uncertainty can become so high for the very large earthquakes at very low probabilities that it has an impact on the overall probabilistic risk assessment of the plant's design.[2] Worse, as the hazard estimate and structure ruggedness play an equal part in protection against seismic risk and in assessment of safety in case of a seismic event, the probabilistic risk assessment of nuclear power plants is based on uncertainty. It can be thus considered useless to try to improve the structure ruggedness or the component-level safety if the hazard estimate remains affected by such high uncertainty. In fact, there is a systemic problem with nuclear power plant's design as, given this uncertainty, it is impossible to use probabilities (neither frequencies nor conventional ones, nor Bayesian), even if we want to assume that we can define an extreme natural event (which is impossible).

As a result, there is always a risk that an unpredictable event that exceeds the design assumptions will occur – which has been the case with the 9.0-magnitude Tohoku earthquake. This possibility of exceeding assumptions has been unfortunately verified during the current nuclear crisis in Japan as Massachusetts Institute of Technology (MIT) experts acknowledge that "nuclear power plants are designed for earthquakes and hurricanes, and in some places tsunamis. But these were unbelievably large".[3] This demonstrates that the assumptions taken into account in the design of the Fukushima-Daiichi reactors were not conservative enough to protect them against such a natural event. More generally, there is no reason to say that assumptions will never be exceeded again or that another similar combination of natural events will never happen again, even with a very low probability of occurrence on paper. This demonstrates the existing systemic uncertainty that cannot be avoided with nuclear design.

Argument #2: "New reactor designs would stand such natural events".

The introduction of the above discussed probabilistic approach to risk assessment to the nuclear industry is due to Norman C Rasmussen, a former professor of nuclear engineering at the MIT in the US. In 1975, he headed the publication of a report for the Nuclear Regulatory Commission (often called the "Rasmussen Report").[4] This report received worldwide attention as it established the formal discipline of PRA, whose methods are now used routinely in nuclear power plant safety assessment. According to the Rasmussen report, the risk of a nuclear power plant failure was low, with a core damage accident occurring only once in every 20,000 years of operation in the US – one reactor running for one year counting as a year of operating experience.[5] But in 1979 – only four years after the Rasmussen report was published – a partial meltdown occurred at the Three Mile Island 2 reactor in Pennsylvania, when the nuclear industry in that country had fewer than 500 years of operating experience. A new study ordered by the Nuclear Regulatory Commission reassessed the risk and estimated it at one meltdown per 1,000 years of reactor operation, 20 times more frequent than assumed in the Rasmussen report. This was the first "lesson learned", facilitating an *improvement* of the PRA-based design of nuclear power plants.

Core Damage Frequency

Nowadays, the current core damage frequency (CDF) of the current generation II reactors is said to be between about 5×10^{-5} per reactor-years or one core damage for every 20,000 reactor years (as expected by Rasmussen in 1975 for the US) in Europe [6] and one for every 50,000 reactor years (or 2×10^{-5}) in the US.[7] With about 440 nuclear reactors currently operating worldwide, this corresponds to one core damage every 45 to 100 years and more. However, with three new core damage accidents at Fukushima-Daiichi nuclear reactors 1, 2 and 3 (with Three Mile Island in 1979 and Chernobyl in 1986), we have had five core damage accidents in less than 40 years. In fact, a core damage has happened every eight years on the average in the world since 1970, corresponding to the beginning of the operation of generation II reactors (very few generation I reactors remain today). This shows a large discrepancy between the safety announced by the nuclear industry and the safety actually measured.

The same day that the three core damages at Fukushima-Daiichi were confirmed,[8] experts at the MIT published an article saying that "new nuclear power plants may not have failed in Japan" (Bullis 2011 in note 2 above). But we obviously cannot know whether or not another reactor would have sustained the same natural events unless a complicated simulation is performed (which also requires us to know exactly the sequence of events that happened at Fukushima). Therefore, comparing one feature to another between different designs is a simplistic approach that does not capture the dynamic sequence of events, which is the one that matters in such nuclear accidents.

In the case of new plants, as shown above, although new safety features are taken into account in the design (i e, reducing the core damage frequency), there will always be a significant uncertainty about whether some assumptions on natural events or component failures will be violated. Statistically, the designed core damage frequency of future generation III + reactors is of the order of magnitude of 5×10^{-7} per reactor-year, depending on the designs.[9] This means that the theoretical nuclear safety would be increased by a factor of 100 with new designs compared to current operating reactors, despite the fact that the generation II core damage frequencies have not even been met for the current reactors. Worse, there is no reason to say that the very low frequency of core damage accidents announced for the generation III+ reactors would actually be met, given the systemic uncertainty affecting core damage frequency estimates as explained before. This actually represents a major limitation on the viability of a large-scale expansion of nuclear energy as an alternative energy source.

Complacency

Therefore, the argument of better safety with new design seems to reflect complacency more than objectivity. Indeed, a good illustration of this complacency towards nuclear energy comes from a recent declaration of French President, Nicolas Sarkozy talking about the design of the new AREVA EPR reactor during the Fukushima nuclear crisis: "The idea of the double wall structure is that if a Boeing 747 crashes on the plant, the reactor is not damaged".[10] That is true. The double wall structure of the EPR reactor building would withstand such an event and it is part of the new safety features of the *future* nuclear EPR reactor. But we cannot predict all other threats or mistakes, not just from the outside but also internal to the plant operation. In any case, there is no EPR reactor currently operating in the world. Only five are under construction while there are about 440 plants operating worldwide. In that case, this argument is not relevant at the time of the nuclear energy crisis in Japan. Therefore, we should be very critical about this kind of official discourse as the following political lock-in we face in general seems to apply to nuclear technology:

> When we act, we create our own reality. And while you're studying that reality... we'll act again, creating other new realities, which you can study too, and that's how things will sort out. We're history's actors…and you, all of you, will be left to just study what we do – attributed to Karl Rove, former advisor of Georges W Bush.[11]

To conclude, I cannot do anything but to urge you not to take as "truthful" the over-reassuring and non-scientifically-based discourse that tends to minimise the seriousness of the nuclear disaster in Japan or which intends to avoid facing the current problems of nuclear energy by talking of future prospects. The history of humankind is already full of such examples.

The existing systemic uncertainty affecting nuclear power plant design raises the question of whether society is willing to accept continuing with a never-ending learning process with potentially high adverse consequences, both to humans and to the environment. It has been argued here that developing new designs will not lead to improved nuclear safety but will simply maintain the technological lock-in put in place by the civilian nuclear industry.

REFERENCES

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[2] We consider here the same distinction between low probabilistic "risk" (randomness with *knowable* probabilities) and "uncertainty" (randomness with *unknowable* probabilities) as introduced in 1921 by Frank Knight (*Risk Uncertainty and Profit)* in the field of Economics.

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[8] The three partial core-meltdown have been confirmed by TEPCO and announced by the French ASN authorities on 15 March 2011 (Press Release No 9). URL: http://www.asn.fr/

[9] E g, UK EPR maximum core damage frequency is equal to 6.1×10^{-7} per reactor-year (http://www.epr-reactor.co.uk/ssmod/liblocal/docs/V3/Volume%202%20-%20Design%20and%20Safety/2.R%20-%20Probabilistic%20Safety%20Assessment/2.R.1%20-%20Level%201%20Probabilistic%20Safety%20Assessment%20-%20v2.pdf).

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