

Preliminary remarks on the EPR project in view of the Fukushima accidents

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The failure of nuclear reactors at Fukushima question the safety of all operating reactors worldwide, but also the ability of new reactors to provide a better safety. The present working paper gathers some provisional remarks that could be addressed to the EPR design in the new light of the Fukushima accidents. It is, however, much too early to draw final conclusions from the return of experience as the catastrophe is going on, and the following is just a preliminary contribution to the debate that will develop on this issue.

Lessons to be learnt from the Fukushima accidents

The series of major accidents on reactors at Fukushima, in Japan, after it was hit on Friday 11 March 2011 by a massive earthquake and a tsunami, question the whole framework of nuclear safety, from objectives to design, assessment and control, as it has been developed in major nuclear countries. Although it is much too early to draw conclusions and a real return of experience from this ongoing catastrophe, it seems already obvious that some essential concepts rooted in the safety of operating reactors worldwide failed.

First, the probabilistic approach, which consists in protecting reactors against a range of events that are considered probable enough to be realistic, led to an insufficient level of protection. This is yet another example that unplanned and most improbable situations can happen.

Second, the in-depth defense, based on the redundancy of safety features and the multiplication of barriers to contain radioactivity, proved insufficient. The plant found itself in a situation where the cooling function, which is key to prevent the nuclear fuel from heating and melting under its own power, was completely lost on all of its six reactors. Partial core melting at reactors n°1 to 3 (reactors n°4 to 6 were under maintenance) and loss of water at spent fuel pools of reactors n°1 to 4 already led, by various mechanism including explosions and fires, to severe breaches of the containment.

Third, these resulted in massive releases of radioactivity to the environment, which are already estimated to a fraction of up to 10% to 20% of those from the Chernobyl accident, and keep increasing as the situation in Fukushima is still not under control. The situation shows how much nuclear reactors, given the high power of their fuel and its concentrated toxicity, are a potential for disaster when their safety goes wrong.

Insufficient safety of existing reactors

These lessons apply to French nuclear reactors. The French nuclear fleet comprises 58 nuclear reactors, all pressurized water reactors of three main standardized models: 34 reactors of 900 MWe, 20 reactors of 1,300 MWe, and 4 reactors of 1,450 MWe. Although differing from boiling water reactors in Fukushima, their design is based on the same probabilistic approach and in-depth defense concept, and their need of constant cooling is the same.

These reactors have been designed, developed and built from the 1970s to the early 1980s for most of them, which did not allow for integrating at a deep level of design the return of experience of previous major nuclear accidents at Three Mile Island in the United States in 1979, and at Chernobyl in the Soviet Union in 1986. In fact, the 42 first French reactors were ordered between 1970 and 1980 and built between 1977 and 1987. Even the four reactors of the latest design, N4 (1,450 MWe), which started commercial operation in the early 2000s, were actually designed in the first half of the 1980s.

Therefore as early as 1995, the French nuclear safety authority (now ASN) stated that it wouldn't give another license to N4 reactors than the four already granted, and that the N4 standard was not acceptable, in terms of safety, to serve as a basis for the future replacement of existing nuclear reactors in France.

Origin and objectives of the EPR project

This need to develop a new reactor, integrating the return of experience of Three Mile Island and Chernobyl to improve the safety of future reactors in France and – at that time – in Germany was the purpose of the EPR project. The project started with the creation by the French nuclear vendor Framatome and its German counterpart Siemens of a joint venture, Nuclear Power International (NPI, later to become part of Areva NP) to design this new reactor.

The conceptual design, based on the French reactor N4 and the German reactor Konvoi, was completed in 1994, with a planned output at that time of 1,450 MWe (or 4,250 MWth). The design combined development from some parts of N4, like the containment, and some parts of Konvoi like the instrumentation. The main features, in terms of safety improvements, were the increased redundancy and level of protection of emergency systems, to reduce the probability of a situation leading to melting of the core, and the inclusion of a “core catcher” to guarantee that, even in the event of a core melt breaching the reactor’s vessel, the core would be retained within the reactor’s building containment, to prevent large releases of radioactivity outside from the plant.

The concepts of the EPR therefore remain based on the same approach of probabilistic assessment and increased depth of defense. It sticks to the principle set by the IPSN (now IRSN, Institut de radioprotection et de sûreté nucléaire, the public institute providing nuclear safety expertise to the French authorities) as early as 1986 that nuclear power plants should be designed in a way to prevent a major nuclear accident, and possibly reduce its consequences when it happens, rather than to search for more revolutionary designs to intrinsically avoid or resist it. In simpler words, this approach leads to create the potential of danger then trying to control it, rather than finding ways not to create such a potential in the first place.

The global goal of the French safety approach for operating reactors has been that the design, assessment and control of the reactors should guarantee that the probability of a major accident, with severe damage to the core is less than 10^{-5} (one for a hundred thousands) per reactor and per year, and that the probability of an event that could lead to unacceptable consequences for the population is less than 10^{-6} (one for one million) per reactor and per year.

The improvement aimed with the EPR can be summarized by getting these probabilities down, respectively to 10^{-6} (one for one million) and to 10^{-7} (one for ten millions) per reactor and per year. But the confidence in such probabilistic calculations is severely damaged after the accidents in Fukushima. The situation there already adds up three cases of severe accidents at reactors to those already experienced at Windscale (Sellafield) in the UK in 1959, Three Mile Island in the USA in 1979, and Chernobyl in Soviet Union in 1986, and one case of massive releases after those at Chernobyl. With a cumulated experience of operation of nuclear reactors worldwide in the range of 20,000 “reactor.years”, this represents an occurrence of severe accident of $3 \cdot 10^{-4}$ per reactor per year, and an occurrence of accident with massive radioactive releases of 10^{-4} , that hardly match the objectives set above.

Increased potential for danger

To address the goal of reducing by a factor 10 the probability of a major accident – whatever sense can be given to this now –, the EPR design relies on an increased complexity which some assessments suggest can be actually an obstacle to the demonstration of its safety.

The basic design phase started in 1995 and was expected to go fast, with the prospect of building a first EPR as early as 2000 in France and have it operating by 2006, also as a demonstration project for exportation. However, some issues could not be fully resolved, e.g. regarding the level of aircraft protection, but the French containment was approved by French (and German) regulators. Still, the basic design work was not completed before August 1997. And while the French Nuclear safety authority had stated in September 1999 that it expected to give its conclusions on a final design certification in the coming months, further assessment would eventually take five years and the French Government issued the generic design approval of the EPR, still not final, in September 2004.

Meanwhile, concerns about the costs associated with new safety features had led to increase the output of the plant, which could reach up to 1,800 MWe. Another way to try to improve the economics of the EPR is to aim for better fuel performance. This includes a design objective of burning the uranium oxide fuel (UOX) up to a unprecedented level of 70 GW.d/ton, posing specific problems of heat and rod containment. This also includes the possibility to use as much as 100% mixed oxide fuel (MOX, made of 7-9% plutonium and depleted uranium) in the core; irradiated MOX fuel has a heat output up to four times higher than UOX fuel and poses lots of reactivity problems, it contains more plutonium which is highly toxic. While trying to reduce the probability of a catastrophe, the process actually let the potential for this catastrophe to increase, both in terms of fuel power and toxicity.

Delays in generic design approval

The Finnish and French regulators both agreed for orders to be placed for the construction of EPRs respectively at Olkiluoto, in Finland in 2003 and Flamanville, in France in 2005. The level of review of the EPR detailed design that had been carried out at that time was not clear, but it is now very clear that this level did not reach that of a comprehensive generic safety assessment. As a result, while construction is going on, although experiencing major delays partly due to the complexity of the reactor, the final generic approval is not granted. In fact, the French nuclear safety authority hinted in 2010 that it would not be in a position, should the construction work in Flamanville be completed at that time, to give approval for the operation of the EPR to start – and this was before the Fukushima accidents and the need to consider their return of experience.

The process of getting approval for the EPR design also appears slower than expected in other countries, especially the United States and the United Kingdom. In the US, Areva NP was expecting some generic approval by 2008 when it started discussions with the nuclear safety regulator, NRC about the EPR design in 2004. When Areva submitted a Standard Design Certification Application to the NRC, in December 2007, it was then expecting the technical review to end by 2010. The process is still going on and the NRC stated that it is not expected now to end before mid-2012, which doesn't include further delays potentially arising from issues pending in France, Finland or UK.

In the UK, the nuclear safety regulator, HSE launched a Generic Design Assessment of the EPR in August 2007 with the prospect to complete it by June 2011. HSE recently indicated that it is likely to deliver an “interim approval” that won't be sufficient to give the green light for construction of an EPR to begin yet in the UK. In the wake of the Fukushima accident, the HSE further indicated that the need to include this return of experience is likely to delay the completion of the ongoing assessment.

Pending issues

One major pending issue that was explicitly a reason for delays in 2010 is the Instrumentation & Control (I&C). The EPR design includes a fully computerized I&C system that is new. The same was already tried in the development and construction phase of the N4 reactors in France, but was eventually dropped in favour of an already proven system, contributing to four years of delays in the completion of these reactors. The concern with the proposed I&C lies in negative interactions that could arise from its complexity and redundancy, where some parts of lower priority of the system are thought to risk to take over some parts of higher priority for safety in some emergency situations.

The issue was first raised publicly by HSE, but it later appeared that ASN in France and STUK in Finland shared the same concern, and the three nuclear safety authorities issued a joint statement in November 2009 to clarify that this had been a matter for discussion for some time and that they were still waiting appropriate responses by the Finnish operator TVO and the French operator EDF and by the constructor Areva. It was reported since that some progress was made, but it doesn't seem that this issue is fully resolved. The NRC, although not party to this public statement, confirmed that this was a critical issue that had yet to be resolved.

Other issues are still being discussed, within the process of safety assessment conducted by regulators or through independent expertises of some aspects of the design. These include the assessment of the probability of an explosion of vapour due to the very energetic reaction between the melted core and the water that might be found in the “core catcher” in the process of an accident, the concerns with

some potential failures of the emergency cooling systems including some clogging, or the disbelief in the hypothesis used in the design that some of the most severe kind of rupture of primary cooling tubes could not happen. Some concerns were also raised through the anonymous disclosure of studies by EDF about the possible reactivity of the core in transients linked to the project to allow fast change of the reactor load to follow power demand.

Finally, some issues were raised regarding the progress made by EPR in terms of security, and its capacity to withstand some kinds of malevolent attacks that have become credible after 11 September 2001. This particularly relates to the resistance of the containment to a commercial plane crash, which is explicitly not included in the basic design of the reactor. It was reported that the studies conducted by the industry concluded that the containment would resist, or at least resist in most cases, but some confidential EDF documents leaked that hinted the opposite. The detail is not known as this falls under national defense secrecy.

Conclusion

After the nuclear accidents in Fukushima, it is no longer possible to put the same confidence on the principles of probabilistic assessment and in-depth defense to guarantee nuclear safety and promote the idea that “a major accident won’t happen”. The whole approach to the safety of existing nuclear reactors needs to be questioned in the view of this complete failure.

The EPR reactor stands as an improvement through complexity but based on the same conception. Its overall goal is to reduce by a factor 10 the low probability of a major accident. The question after Fukushima is whether the whole rationale behind this probability factor is right, as we witness that the probability proves wrong.

Moreover, the accidents highlight the potential of catastrophic release that the core and the spent fuel represent once the various barriers have failed. One lesson from Fukushima might be to re-open the reflexion on other approaches, which aim for reducing the potential itself instead of the probability of this potential to be realized. This includes reducing the size of reactors but also thinking of more inherently safe concepts of reactors. Actually, some of them have already been tried, like the high-temperature gas-cooled graphite reactor, where fuel is in the form of small particles, each of them coated by a containing material, in the 1960s – not to say that this is the answer, but just to recall that other approaches, some failed but others dropped due to their economics, have already been explored and that there surely are more in the light of modern technologies.

The EPR, which relies on an increased power, aims for higher burnup of fuels and even for the use of plutonium fuel (MOX), just follows the opposite path of increasing the potential of danger.

The complexity of the safety features involved is the cause of concerns for their effectiveness and some negative interactions between them. It raises obstacles for a full demonstration and approval by regulators of the safety of the EPR generic design. Overall, this demonstration has to rely on the same confidence of engineers in their “probabilistic approach”, that had just been beaten. The “safer reactor in the world”, as the French industry brands it, seems based on outdated concepts even before it’s operated.