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Summary in English of

Post-Fukushima Nuclear Safety in France:

Analysis of the Complementary Safety Assessments (CSAs) Prepared About French Nuclear Facilities

by

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Translators' Preface

This English translation of the summary of the report, *Post Fukushima Nuclear Safety in France*, was prepared because much of the report is applicable to other countries where there are light water nuclear power reactors, especially pressurized water reactors, and where there are reprocessing plants. We have also translated the Table of Contents, in case readers want to refer to the full report in French for more details on the topics listed. The report was written by Arjun Makhijani of IEER and Yves Marignac of WISE-Paris for Greenpeace France and published on 20 February 2012. The entire report in French is available at http://www.greenpeace.org//france/PageFiles/300718/120217RapportECS-IEER-WISE-Paris.pdf or at http://www.ieer.org/reports/NuclearSafetyFrance_2012-RapportECS.pdf

Since the summary was originally designed to accompany the full report, we have inserted a few translators' footnotes as well as some phrases in square brackets in the text to clarify the context and/or intent of certain sentences or passages in this standalone summary.

Translators:
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Summary

Conclusions and recommendations

The March 11, 2011, Fukushima Dai-ichi nuclear catastrophe in Japan has definitively demonstrated that accidents heretofore considered too improbable to protect against can indeed occur. In order to address the multiple and unprecedented nuclear safety failures thus revealed, the French government rapidly put in place a process for complementary safety assessments (CSAs called "Evaluation complémentaire de Sûreté or ECS in French) for the principal nuclear facilities. The CSA reports prepared by the operators of these facilities [Electricité de France (EDF) and Areva[1]] were published in September 2011. The analysis of the Institute for Nuclear Safety and Radiation Protection (Institut pour la sûreté nucléaire et la radioprotection, or IRSN) of these CSA reports was published in November 2011. These unprecedented transparency measures were accompanied by a dialogue involving the concerned national and local authorities. This paved the way for a pluralistic expert consideration of safety.

The present report provides a critical analysis ranging from the scope of CSAs to the review of the CSAs by the IRSN. It evaluates the CSAs produced by EDF for three nuclear power plants ([the 900 MWe reactors at] Gravelines, [the 1,300 MWe reactors at] Flamanville and [the 1,450 MWe reactors at] Civaux) representing the three reactor models in the French nuclear power fleet, the CSA produced by EDF for the [1,650 MWe] EPR reactor under construction [at Flamanville], and the CSA produced by Areva for its reprocessing facilities at La Hague. At this stage, our analysis addresses technical considerations and does not address the conclusions and recommendations of the [French] Nuclear Safety Authority (Autorité de sûreté nucléaire, or ASN) about the CSAs. Given the limited time and resources available for this study, we did not try to examine all essential questions and problems. Rather, we focused on some essential questions and formulated recommendations that we hope will be useful elements to the nuclear safety debate in France.

It is important to underline the strengths of the CSAs. Types of accidents and their consequences that were not considered at the design stage and during the operations of nuclear facilities have, for the first time, been examined. In keeping with their required scope, the CSAs systematically examine accident scenarios that could be initiated by earthquakes or floods, including accidents beyond the design basis of the facilities, as well as the consequences of a loss of electric power and/or of the sources of cooling water supply. Finally, [some of] the additional equipment that should be put into place to prevent large radioactivity releases is described in detail and proposals for the reinforcement of existing facilities have been discussed. As a result, the CSAs provide a first important look at nuclear safety in France and measures that may be necessary to reduce the risks of the kinds of serious accidents that Fukushima indicates are possible.

Principal conclusions

Our analysis that accident scenarios beyond those considered in the CSAs should be considered plausible and evaluated in light of Fukushima. [These scenarios for existing reactors, the EPR and La Hague are]:

- for the 58 reactors operated by EDF, independent of the model of the reactor
  - a core meltdown accident can lead to a breach of the containment of the reactor (leading to major radioactivity releases to the atmosphere) and/or a total penetration of the reactor building] slab [potentially leading to groundwater contamination],
  - loss of cooling of the spent fuel pool can lead to a spent fuel fire and large-scale releases of radioactivity due to the lack of a spent fuel building containment structure [similar to the reactor building containment].

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[1] Translators' note: Le Commissariat à l'énergie atomique (CEA, the French Atomic Energy Commission) and l'Institut Laue Langevin (ILL, a nuclear research center) also produced CSA reports. These were not addressed in the report summarized here. The mixed oxide fuel plant known as MELOX was also not addressed.

- The same risks [as for reactors in the existing fleet] cannot be excluded for the EPR project.
- A major accident involving a spent fuel pool or stored high level liquid radioactive wastes could occur at the La Hague reprocessing plant [due to prolonged loss of cooling and/or electric power supply].

The CSA reports are an important starting point for reinforcing the safety of nuclear facilities but they are too limited in scope to be a definitive basis for decisions [regarding nuclear safety].

The limitations of the required scope [of the CSAs] as well as the interpretation of the scope by the plant operators have created important weaknesses in the CSA reports:

1. A general reservation in regard to the actual state of the facilities in the analysis of the facility operators is that, overall, they did not rely on some of the latest studies. Many of their conclusions are based on "engineering judgment" and the confidence [of technical experts] in the quality of the design and construction of the facilities.
2. The list of factors that could initiate or aggravate accidents is not complete in the CSAs, which are therefore not all-inclusive of accident scenarios. The following elements are lacking or have not been sufficiently developed in the CSAs
   a) scenarios initiated by material equipment failures, human errors, and malevolent acts;
   b) secondary failures and incidents that could result from an earthquake or a flood and from the failure of electricity and/or cooling, notably (i) breaks in primary or secondary reactor cooling systems, (ii) an accidental drop of a fuel assembly in the course of transfer to the spent fuel pool from the reactor or of a spent fuel transport container in the course of transfer [of spent fuel from the container] to the spent fuel pool, (iii) fires, and (iv) explosions, including hydrogen explosions, in reactors and chemical red oil explosions at La Hague.
3. Factors that could make the management of an accident more difficult, notably the contamination of the site due to the failure of secondary, non-safety-rated facilities have not been taken into account. The contamination of the site was one of the most important difficulties confronted by the authorities and workers in managing the Fukushima accident. That accident also has shown that offsite contamination can complicate the mobilization of offsite resources for use at the site and cause the diversion of resources, such as radioprotection personnel [to offsite needs].
4. Several important generic questions were not examined [in the CSAs]. Among them:
   a) the limits imposed by the design of the reactor cores and of the spent fuel pools at the reactor sites and at La Hague.
   b) the role that aging plays in the aggravation of the consequences of accidents. The CSAs are based on the theoretical state of the facilities as of mid-2011 and do not take into account aging which increases the risk of failure of safety equipment and of the non-replaceable elements of the system (such as reactor vessels and containment structures)
5. In general, the proposals, developed as part of the "hardened core" for [assuring] electricity supply and cooling and of the reinforcement of the means for managing accidents, address how accidents will be managed after they start without reducing the potential for an accident. For instance, the following are not discussed in the CSAs:
   a) the risks of using zircaloy as fuel cladding material. Zirconium plays a central role in core meltdown and in the production of hydrogen once certain accidents start, such as those at Three Mile Island and Fukushima. But the possibility of replacing zirconium by an alternative material was not introduced;
   b) the use of MOX fuel[2] as a factor that could aggravate reactor accidents or the risks created by the storage of large amounts of spent fuel at La Hague of which MOX spent fuel is an important part.

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[2] Translators' note: MOX fuel is a mixture of plutonium dioxide and uranium dioxide. The more common fuel for light water reactors is low-enriched uranium dioxide (UOX).

Principal recommendations

The CSA reports should be revised according to a more complete scope that includes internal and external initiating factors and management of accidents that include contamination onsite and offsite. The analyses should also take better account of the uncertainties in the conclusions [regarding accident risks and consequences]. Further, the CSA reports should take into account the actual state of the facilities.

It seems necessary to expand the circle of experts who contribute to the evaluation process; this would be a way of putting in place a more complete approach to the debate and for defining new elements of safety and their implementation. In this context, a systematic survey of various approaches to the CSAs should be done and independent reviews should be included at the most critical points in the process. Specifically, this process should include the implementation of improvements to the CSAs recommended below.

Reactor accident scenarios: There are significant limitations in the accident scenarios that EDF examined [in the reactor CSAs]. Besides the limitations of the scope of the CSAs, EDF systematically excluded all hypotheses in which accidents could be made more serious by failures induced during the course of the accidents themselves. Further, EDF has also excluded the worst-case phenomena for reactor accidents of the rupture of the containment structure by an explosion or of the penetration of the reactor building slab [by corium[3]]. EDF only retained for study the cases, such as a slow pressurization of the containment, that would have the lowest consequences. Finally, EDF only examined accident scenarios in which boiling was the mechanism for loss of spent fuel pool cooling, though other scenarios could lead to a loss of cooling water from the pools and lead to much more serious consequences; these should also have been examined.

Recommendations regarding the accident scenarios for the reactors:

1. EDF should complete the CSA studies and analyze the scenarios it has so far excluded in a determinist[4] fashion. These accidents should include those initiated by equipment failures or by human action, fires, explosions, or [accidental] load drops induced in various ways.
2. The ECS reports should analyze the consequences of currently excluded scenarios such as vapor or steam explosions or the penetration of the slab of the reactor building [by corium].
3. EDF should conduct site-specific accident studies on the consequences of spent fuel pool accidents. In particular, the low level of protection[5] against a loss of cooling water from the spent fuel pool and its consequences should be taken into account.

Zircaloy: The fuel cladding is made from an alloy called zircaloy, which consists mainly of the element zirconium. The uncovering of the fuel due to a loss of coolant from the reactor vessel triggers a series of events that can lead to a core meltdown. Zircaloy plays a central role in this series of events as well as in the production of hydrogen and in the risk of an explosion. Despite this, none of the CSAs considers the possibility of an alternative cladding material to replace zircaloy.

Recommendation regarding zircaloy:

1. [One of] the criteria for substitute materials should be to eliminate or greatly reduce the generation of hydrogen. This would considerably reduce the probability of a serious accident that results in releases of radioactivity. A systematic research and development program to find a substitute for zircaloy, with the goal of reducing the probability of a serious accident that leads to a core meltdown, should be put into place.

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[3] Translators' note: Corium is the molten mix of fuel and cladding material producing during a core meltdown accident.

[4] Translators' note: "determinist" in this context means inclusion of accident scenarios independent of their probabilities of occurrence. Hence a "determinist" approach does not exclude accidents that are considered very low probability events.

[5] Translators' note: Low level of protection compared to the reactor.

MOX fuel: Twenty-two 900 MWe reactors [in France] are licensed to use a fuel that is a mixture of the dioxides of plutonium and uranium (MOX fuel) for up to 30 percent of the core. Twenty-one of these reactors are currently using MOX fuel. MOX fuel presents a set of safety problems in case of an accident and its storage in spent fuel pools is more complicated due to its greater thermal source term. The consequences of the meltdown of a core that includes MOX fuel or of a fire in a spent fuel pool in which MOX is stored could also be much more serious than those involving uranium dioxide fuel (UOX) alone. The CSAs do not take these differences into account. The considerations are important for all the sites where MOX fuel is used but especially so for Gravelines, where all six reactors are authorized to use MOX and five of them are currently using it. This issue is also important for La Hague where at least 900 metric tons of MOX, mainly MOX spent fuel, are stored. This is a larger quantity of MOX than the combined total in the reactors or spent fuel pools of all the nuclear power plants [in France] that use MOX. While the thermal source term of the MOX spent fuel stored at the reactor sites is too great for dry storage, most of the MOX at La Hague could be put into dry storage, which, overall, is much safer than spent fuel pool storage.

Recommendations regarding MOX

1. The risks and consequences of the use of MOX, including MOX spent fuel storage, should be explicitly examined in the CSA study process.
2. The reduction of risks that could be achieved by stopping the use of MOX fuel should also be examined in the CSAs.
3. Further, the reduction of spent fuel stored in the pools would reduce the risks and the consequences of spent fuel pool accidents. The CSAs should examine the extent to which risks would be reduced by dry storage of sufficiently cooled MOX spent fuel.

The design basis of the reactors [in the French civilian fleet]:: The choices that were made at the stage of reactor design and since the construction of the different reactor facilities have a determining role in their capacity to resist accidents that were not part of the set of scenarios that were included at the time.

a) There are differences in design between the [three] reactor models in the French fleet. The 1,300 MWe and 1,450 MWe reactors have a double-walled containment structure consisting of one reinforced concrete and one prestressed concrete structure, while the 900 MWe reactors have a single-walled containment structure with an inner metallic liner to assure that the containment is sealed. The double-walled structure was designed to provide better resistance to external initiating events. But the absence of an inner metallic liner has made those reactors more vulnerable to disruption from internal threats such as hydrogen explosions. EDF has not examined the differences in strength between the different models in the French nuclear reactor fleet.

b) Spent fuel pools were not designed with the same degree of care and protection from the point of view of safety because in the initial decades of nuclear power, only reactor accidents were considered important. As a result, the spent fuel pool buildings are not designed to the same level of safety as reactor containment buildings and do not offer the same level of protection against internal and external threats. The Fukushima accident has clearly demonstrated the risks associated with spent fuel pools. Moreover, the total quantity of long-lived radionuclides, notably cesium-137 (the main long-lived contaminant after Chernobyl and Fukushima) at La Hague is far greater than in any reactor. Given this reality, it is important to consider the reinforcement and management [of spent fuel and its storage].

Recommendations regarding design issues:

1. EDF's CSAs should consider the differences in design between the various reactor models and the consequences of these differences for resisting internal and external threats. This will enable an assessment of the differences in strengths of the various facilities under different accident scenarios in the context of the CSAs and of their revision.
2. The analysis of design differences would support consideration of the feasibility of using various techniques to reinforce the weaker designs so that a level of safety that is as uniform as possible can be achieved across all reactor facilities. These considerations particularly apply to the weaknesses of the different containment buildings and spent fuel pool buildings.

3. Adapting facility management should also be given consideration. For example, the time for which a reactor core should be cooled in the reactor vessel [before transfer to the spent fuel pool] should be revised with the objective of reducing emissions of iodine-131 to a level as low as possible in case of a [spent fuel pool] accident. The CSAs should also explicitly consider which arrangements of spent fuel in the pools would most reduce the risks of the propagation of a fire.

Actual state of facilities and aging: The gaps between the design basis and the actual state of the facilities can create risks that need to be understood in order to address them and also in order to address the possibility of undetected differences between the actual state of the facilities and their design basis.

Further, aging and use reduces the safety margins originally built into the various pieces of safety equipment at the time of their design. It is important to recall in this context that the reactors were built to operate for at least 30 years but not more than 40 years. Again, aging can weaken equipment, notably components that are non-replaceable and lower the level at which they would fail due to thermal or mechanical shocks. No reinforcement can completely overcome the limits imposed by aging. Thus, some of the containments of the 1, 300 MWe and 1,450 MWe reactors have already degraded, while several of the 900 MWe reactor vessels have lower safety margins relative to a rupture that may not be adequate even for 40 years of operation. Moreover, with time, usage creates a diffuse and increasing risk of safety failures.

Recommendations regarding conformity to design and aging:

1. The CSA reports should more carefully examine the conformity of the actual state of all relevant facilities with their design basis in the context of relevant accident scenarios. The impact of known or anticipated non-conformities should be discussed.
2. Aging mechanisms should be taken into account in the approach taken in the CSA studies. First the impact of identified aging mechanisms on accident scenarios should be examined; second, the sensitivity of equipment failure to undetected aging should be considered. Specifically, the CSAs should analyze the contribution of these problems to acceleration of threshold effects in accident scenarios.
3. Gaps between the design basis and the actual state [of facilities] can define reinforcement objectives. An examination of safety issues in light of these considerations would allow a better definition of acceptable levels of differences between design basis and the actual state of the facilities.

The EPR: The EPR was conceived as a reactor that would be better able to withstand various types of threats and events and at the same time to reduce the consequences of serious accidents. Nonetheless, its design basis needs to be re-examined in light of the Fukushima accident. The first elements of the re-examination were the vulnerability to flooding of the emergency diesel generators at the Flamanville site of the EPR, the protection of the control room from the effects of reactor core accidents, and the degree of safety of the spent fuel pool. Even before this [post-Fukushima] discussion, it is important to remember that the generic demonstration of the safety of the EPR design was not fully settled regarding issues as critical as its control system and its innovative reactor building slab that is designed to catch corium [in case the corium melts through the reactor vessel during a core meltdown accident]. In addition, there have been many problems of non-conformity during construction [at Flamanville].

Recommendations for the EPR:

1. EDF's CSA for the EPR should be as specific as possible about the topics that remain open regarding the safety of the reactor. This would allow an assessment of EDF's conclusions in light of the uncertainties [regarding safety issues].
2. EDF should also identify the non-conformities identified during construction [at Flamanville] and how they have been or will be handled. The [CSA] report should at least address how the more important non-conformities might affect behavior of the reactor in the identified accident scenarios, and in particular any threshold effects or cumulative effects that they might entail. In light of the risk that there might be undetected non-conformities, the [revised] CSA report should have a sensitivity analysis that assesses their impact on the results of the CSA.

3. Further, the range of scenarios should be expanded to include the types of considerations discussed above for the existing reactors in France (initiating events, secondary damage induced by the accident, the consequences of accidents addressed in a deterministic fashion…)

The reprocessing plants at La Hague: Besides the spent fuel stored in pools, La Hague has a vast quantity of highly radioactive liquid waste that needs to be cooled. A complete loss of cooling for a few days could results in an explosion and dispersal of a huge amount of radioactive contamination over a large area. In 1957, an explosion in a high-level waste tank in the Soviet Union caused contamination over a vast area that still persists. [In 2009,] the Norwegian radiation protection authority estimated that emissions of highly radioactive liquid waste from tanks at Sellafield, in northwestern England, could produce cesium-137 contamination [in Norway] ranging from one-tenth to fifty times that produced in Norway by the Chernobyl accident.

Then there is the issue of formation of red oil when a mixture of organic chemicals comes into contact with acid at elevated temperatures. Flow control of various material streams and temperature control as well as the capability to take countervailing measures are important for avoiding red oil explosions. Several explosions have occurred in the United States in the past and, more recently, in 1993 in Russia, where a part of the reprocessing building was destroyed by the force of [one of] the [two] explosions. The IRSN has published a technical document on this topic on 2008. Yet, Areva has not examined the problem of red oil explosions in the post-Fukushima CSA context – that is, in the context of a total loss of cooling and/or electric power supply.

Recommendations for La Hague:

1. Areva's CSA for La Hague should be strengthened in regard to spent fuel pool accidents and their consequences. The low level of protection against a loss of cooling water from the pool should be taken into account. [6]
2. Areva should examine the fault trees for potential accidents so that more complete mitigation measures can be put in place.
3. Areva should examine the possibility of combining dry cask spent fuel storage with low density storage in spent fuel pools [at La Hague], which would significantly increase the time required for boiling [in case of loss of cooling water supply].
4. Areva should examine the possibility of reducing the inventory of spent fuel stored at La Hague by increasing storage at reactor sites in low-density configurations in the pools and dry storage. The spent fuel inventory at La Hague could be reduced to the minimum necessary for smooth management of reprocessing operations.
5. If possible, the secondary sources [of liquid radioactive waste], which are still significant, should be treated as soon as possible, thereby eliminating source terms that could complicate the management of accidents.

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[6] Translators'note: "low level" relative to reactors.