REPORT

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

Post-Fukushima Complementary Safety Assessments: behaviour of French nuclear facilities in the event of extreme situations and relevance of the proposed improvements

Translation of IRSN REPORT N°708
February 2012

Summary of IRSN report No.679, which served as the basis for the meetings of the advisory committees for reactors and for laboratories and plants held on 8, 9 and 10 November 2011

1. INTRODUCTION

Following the accident that occurred on the Fukushima Daiichi nuclear power plant on 11th March 2011, the prime minister asked the French nuclear safety authority (ASN) to carry out an audit on the safety of French nuclear facilities. On 5th May 2011, ASN issued twelve decisions requiring the French nuclear licensees to perform complementary safety assessments (CSAs) of their facilities, based on the specifications attached to the aforementioned decisions and consistent with the specifications for the stress tests requested by the European Council.

The CSAs with the aim of taking into account the first lessons learned from the events that hit the Fukushima Daiichi NPP, evaluate the capacity of French nuclear facilities to withstand extreme situations beyond design basis assumptions. In 2011, these evaluations included the power reactors in operation (900, 1300 and 1450 MWe PWRs) or under construction (EPR), as well as certain nuclear facilities considered by ASN to be priority like the High Flux Reactor in Grenoble, the Jules Horowitz reactor, the OSIRIS reactor, the MASURCA plant, ATPu plutonium technology facility, the PHENIX plant, the MELOX plant, the La Hague facilities, the FBFC and, on the Tricastin site, the AREVA NC, COMURHEX, EURODIF, Georges Besse II and SOCATRI facilities.

In this context, ASN asked the advisory committees for reactors (GPR) and for laboratories and plants (GPU) to submit their opinion both on these complementary safety assessments and on the relevance of the improvements proposed by the licensees to enhance the safety of their facilities in the event of extreme situations (earthquake, flood, loss of electrical power supply, loss of heat sinks), based on IRSN's critical assessment. These advisory committees of experts notified ASN of their opinion on the methodology proposed by each licensee at a first meeting held on 6th July 2011. On the basis of GPR and GPU position, ASN then informed the licensees of the points requiring particular attention

IRSN's review of the CSAs performed and submitted by the licensees on 15th September 2011, was the subject of a report forwarded to ASN and to the members of the advisory committees on 4th November 2011 (this report – IRSN Report n°708 - is available in French at www.irsn.fr). The present report is its summary.

2. INTERNATIONAL CONTEXT

To the knowledge of IRSN, abroad, only power reactors are covered by complementary safety assessments. To provide some items for the comparison of the approaches adopted, the IRSN report presents summarily the positions taken by the relevant authorities after the Fukushima accident in three nuclear countries—the United States, the United Kingdom and Finland—.

Although they all consider that continuing reactor operation does not present any imminent risk for the public, the safety authorities of these three countries agree that the safety requirements for certain situations caused by hazards or hazards combinations must be reinforced. Furthermore, they believe that certain issues should be re-examined, which may lead to the implementation of additional organisational, material or procedural measures.

3. IRSN ANALYSIS APPROACH

In view of the safety approach, the design basis and the ten-yearly safety reviews, the facilities should be considered robust with respect to the hazards taken into consideration in the safety demonstration. As a matter of fact, as part of the safety reviews, the level of design hazards is reviewed periodically, which, over time, ensures the robustness of the facilities to hazards, including external hazards. However, the real condition of the facilities may temporarily affect this robustness due to non compliance to safety requirements. Moreover, changes to available knowledge concerning hazards may compromise this robustness. In any case, the current safety demonstrations do not theoretically guarantee the proper behaviour of the facilities for beyond design basis hazards (hazards beyond those considered in the safety demonstration).

Consequently, the approach required in the CSAs consists in considering that extreme situations are possible as a result of natural external hazards or that, independently of any hazard, accidental situations may present features (e.g. duration, number of facilities involved, etc.) exceeding the safety requirements. To this end, the CSAs must identify the safety functions to be ensured in those extreme situations, like earthquakes, flooding, long-term loss of cooling, loss of electrical power supply, to avoid dreaded situations (core meltdown, uncovering of fuel assemblies stored in a spent fuel pool, significant releases, etc.). This approach intends to avoid serious consequences that a beyond design basis hazard accident situation could have on the environment and the public and is divided into two phases:

- verification of equipments and structures compliance, which constitutes a prerequisite for facility robustness,
- an approach based on defence-in-depth beyond the assumptions considered in the safety demonstration.

IRSN assessed the methodologies adopted by the licensees for the CSA. The methodologies implemented were on the whole considered satisfactory, and any additional items deemed necessary were identified and taken into account.

IRSN chose to organise its report around topics, rather than around each licensee. IRSN also defined an analysis approach based on the defence-in-depth principle for a consistent analysis of the relevance and adequacy of the licensees' proposals.

This approach implies that, in addition to the current safety provisions, a "hardened safety core" of structures, systems and components (SSCs) shall be identified, knowing that their availability, in all considered scenarios, enables the control of the three essential safety functions to be ensured: controlled reactivity, heat removal and containment of radioactive materials.

Thus, the issue of the operational aspect of the systems and equipments contributing to safety and radiation protection, which is always questionable considering the various sources of uncertainty (hazards, behaviour of facilities in extreme situations, etc.), will be replaced by the issue of deterministic protection of a reduced scope of SSCs for beyond design basis hazards.

Following the conclusions of the advisory committees of experts and the ASN's decisions, each licensee will have to propose a precise definition of the "hardened safety core" to be implemented for each of its facility, identifying the level of "CSA hazards" for which the SSCs must be designed. An implementation schedule taking account of the particular sensitivity of certain sites or facilities shall be proposed.

In parallel, experience feedback from the Fukushima accident as well as the CSAs assessment highlighted certain limits for the current safety demonstration. For example, the current demonstration does not postulate, or only occasionally, a total loss of cooling or energy sources affecting several facilities on one site. IRSN believes that these assumptions must be reexamined before the next safety reviews.

4. FACILITY COMPLIANCE WITH SAFETY REQUIREMENTS

Control of facility compliance with applicable safety requirements is an essential condition of safety. As a matter of fact, facility compliance ensures the capability of facilities to withstand the accidents postulated in the safety demonstration and thus constitutes a prerequisite of facility robustness for the situations considered in the CSAs. In this respect, all the licensees have undertaken to complete - by the end of 2012 - the reviews carried out in the framework of the complementary safety assessments in order to confirm that there are no non-compliance in the structures, systems and components contributing to the management of accident situations involving a loss of cooling or energy sources or of a severe accident.

More generally, maintaining the facility in compliance with its safety requirements requires processes that must be designed, managed and led rigorously. Licensees did not detail their organisational measures in the CSA. However, IRSN believes that several measures are necessary to sustain compliance: the integration of national processes with processes particular to each site, the operational control of the processes, the traceability management required at the different steps of the processes, and the sustainability of the qualification of equipment and systems are important aspects for increasing confidence levels in knowledge of the real condition of the facilities. IRSN believes that the reflection work and actions initiated by the licensees in these areas must continue.

IRSN considers that the main known non-compliances affecting safety have been taken into account by EDF. IRSN confirms, however, the need to anticipate corrective actions in the light of experience feedback from the Fukushima accident for some of them. For example, insufficiency in reserves of auxiliary feedwater to put the unit into a safer state in the event of an offsite power loss should be addressed. Furthermore, the lack of earthquake requirements for the venting system of backup diesel generators in some 1300-MWe reactors should be rapidly corrected.

Finally, as a number of inspections are scheduled during periodic reviews and that modifications and new safety objectives are planned to be integrated during the ten-yearly reviews, IRSN considers that EDF should place priority on the implementation of inspections and modifications ensuring compliance, of both the SSCs involved in the management of facilities in the event of a total loss of electrical power supplies and the SSCs ensuring the absence of induced hazards (e.g. hazard induced by an earthquake or a flood, such as a fire) that would make ineffective the operation of the facility. As an example, IRSN pointed out that the robustness of the facilities with regard to an induced hydrogen explosion relies on modifications on hydrogen pipes associated, at this stage, with the third ten-yearly reviews for the 900 and 1300 MWe series and the first ten-yearly review for the 1450 MWe series.

5. FACILITY ROBUSTNESS FOR BEYOND DESIGN BASIS HAZARDS

Concerning **seismic hazards**, IRSN notices that seismic knowledge is rapidly increasing (revision of historic seismic characteristic estimates such as that of Bale in 1356 or Lambesc in 1909, knowledge of active faults, improvement in calculation methods, etc.). In the light of improved methods and knowledge, experience feedback from the application of basic safety rule RFS 2001-01 and conclusions from the international seminar organised by ASN in 2009, IRSN considers on the whole that three areas for improvement in the evaluation of seismic hazards can be identified:

- continued improvement in basic data (to improve the evaluation of seismic hazards and reduce associated uncertainties),
- the explicit integration of uncertainties in the calculation of seismic hazards: to this end, IRSN recommends the combined use of a deterministic approach and a probabilistic approach that are complementary,
- the consideration of the diversity of expert opinions: geological and seismological data may lead to different interpretations; IRSN believes that multiple assessments should be considered in the calculation of seismic hazards.

These aspects should be investigated for some sites in priority.

As regards beyond design basis earthquakes, the licensees have presented simplified calculation methods and test results as well as methodologies to evaluate the overall margins for civil engineering structures, systems and components (SSCs), notably on the basis of currently available data in the field of seismology and on an "engineer's opinion".

While emphasising the difficulty in completing this exercise within the deadlines, IRSN notices that the uncertainties concerning the characterisation of seismic movements to be considered for the CSAs and the simplified methods for evaluating the seismic behaviour of the facilities do not enable the robustness of each facility to be evaluated with a sufficient level of confidence. In particular, these simplified methods do not allow considering the values of global margin factors described by the licensees as a reliable representation of the robustness of the facilities in the event of an earthquake. In order to evaluate effective robustness, it would have been necessary to identify the weakest elements limiting the facility robustness, which was not compatible with the CSA deadlines.

Generally speaking, even if the licensee evaluations exhibit margins, the integration of uncertainties, including those linked to the level of seismic hazard, and the impossibility of considering that the margins identified by the licensees could be uniform at the structure level, require additional checks to support the civil engineering structures capacity to contribute to the availability of the SSCs constituting the “CSA hardened safety core” (protection, equipment support, participation in containment).

Moreover, IRSN considers it necessary to apply the defence-in-depth concept and thus verify the robustness of the SSCs contributing to the prevention of situations with total loss of the heat sink (pumping station) or electrical power supply (electrical rooms, rooms housing backup diesel generator sets, etc.).

Flooding may result from various phenomena; Incorporation of this hazard into the design is based on the identification of all possible sources of flooding. The evaluation of consequences on a case-by-case basis makes it possible to consider that some situations are covered by others. There are two types of phenomena: one leading to significant quantities of water on the sites (river-floods, etc.), the other one leading to smaller quantities (rain, etc.) but directly in the vicinity of the buildings. The protective measures adapted to one type of phenomenon are not necessarily effective for the other.

Considering the diversity of site configurations and possible combinations of hazards, as well as the deadlines, IRSN believes that the analysis of facility robustness beyond design can be performed pragmatically, by identifying a few hazards representative of risks of massive or local water inflows on the sites and by evaluating the capacity of the site to withstand flooding levels above those caused by design basis hazards. This evaluation in the CSAs may be performed by envisaging increased hazard scenarios (approach used by EDF, the ILL and AREVA for the Tricastin site) or by making good use of significant margins towards design basis hazards (approach used elsewhere).

In the first case, it is necessary to check that the increased scenarios are actually representative and envelope, and to study whether there are any cliff-edge[1] effects for these increased scenarios. In the second case, the adequacy of the margin with regard to a cliff-edge effect must be evaluated. In both cases, the goal is to identify the measures to be implemented to improve the robustness of the facility beyond the design basis. This approach must be supplemented by taking into consideration the effects linked to flooding and the extreme meteorological conditions that often accompany floods.

During its assessment, IRSN emphasised the need to go deeper into some of the licensees' analyses to confirm their conclusions and define the improvements to be implemented. In most cases, the licensees have provided supplements that are overall satisfactory. However, concerning risks linked to rain, IRSN considers that EDF's proposals regarding the assumptions used for the characterisation of the phenomenon and the CEA's proposals for the integration of flow conditions are not totally satisfactory.

With respect to defence-in-depth, IRSN also found it necessary to reinforce, at the present stage, the consideration of flood risk exceeding the design basis, for example through an increase in the protection of the installation against flooding. As a matter of fact, this provision strengthens the robustness of the facilities to prevent situations of total loss of the heat sink and electrical power supplies, in the event of flooding that may exceed the design basis hazard, without however reaching the level envisaged in the CSAs.

The report also addresses nuclear facility hazard risks from **the effects caused by external hazards covered by the CSAs on industrial facilities or nearby communication lines.** IRSN underlines that the analyses carried out by the licensees are based on the elements in their possession, as they do not have all the information necessary to assess the robustness of off-site industrial facilities with regard to an earthquake or flooding. IRSN believes that the licensees should:

- take account, in a deterministic manner, of the dangerous phenomena related to hazards in industrial facilities and evaluate their effect on nuclear facilities,
- evaluate the consequences of hazards related to communication lines on nuclear facilities,

by considering the condition of their facilities following an earthquake or flooding.

These evaluations will have to be performed on certain sites such as Gravelines, Saint Alban or the Tricastin site in priority. They will be considered to define the requirements for the "CSA hardened safety core", in particular regarding emergency management resources.

[1] High discontinuity in the scenario causing notable and irreversible aggravation of the accident (significant increase in releases, significant decrease in time before undesirable situation is reached, etc.).

Finally, IRSN assessed the methodologies for taking account of the events or **effects induced in the facilities (fire, explosion, etc.)** by natural hazards exceeding the design bases.

IRSN underlines that EDF has not postulated any fire or explosion caused by an earthquake. Furthermore, the seismic level used for the design of fire sectoring, detection means and fire fighting varies depending on NPP series. IRSN believes that EDF should carry out studies to justify the robustness of its facilities with regard to a fire (or explosion) caused by a beyond design basis earthquake, and *a fortiori* the absence of a cliff-edge effect on the SSCs and on the "CSA hardened safety core".

IRSN also noted that the CEA, AREVA and the ILL have studied fire or explosion as direct aggravating factors of the effects of an earthquake or flood and have concluded that these situations would not lead to any cliff-edge effect. However, IRSN believes that the demonstrations should be supplemented by an examination of the risk of fire propagation or explosion, initiated after an earthquake or a flood, capable of affecting the SSCs that are crucial to the control of safety functions.

6. BEHAVIOUR OF FACILITIES IN THE EVENT OF LONG-LASTING TOTAL LOSS OF COOLING OR ENERGY SOURCES AFFECTING SEVERAL FACILITIES ON THE SAME SITE

EDF REACTORS

EDF analysed situations with a loss of the reactor heat sink and electrical power supplies, beyond the design bases, considering, in particular, that the postulated situations are assumed, on the one hand, to affect all the reactors of one site and for a long period of time and, on the other hand, to be induced by an external flood or earthquake. For these situations, the reports provided by EDF show that some scenarios can lead to the beginning of a core meltdown within a short period of time (a few hours to one day). According to IRSN, these scenarios need to foresee additional means on the sites as well as off-site emergency means. It is important that these means should, as a priority, enable a severe accident with core meltdown to be avoided rather than just managing the consequences of such an accident.

On the basis of this conclusion, EDF proposed a number of studies and material and procedural improvements in this direction. These provisions contributing to preventing core meltdown in the situations postulated in the CSAs will be robust on hazard levels greater than those of the design bases and will constitute the future "hardened safety core" to be defined. IRSN considers this to be a positive step.

As regards, more particularly, the spent fuel pools of its facilities, EDF studied the consequences of a major natural hazard on the cooling systems by examining the consequences of a loss of the heat sink or electrical power supplies. In these situations, EDF concludes that, for the residual heat removal, a pool water make-up must be ensured over the long term, to compensate for the effect of boiling induced by the loss of cooling. This is integrated into EDF's action plan. However, IRSN considers that, in the event of an earthquake of a level greater than that of the design earthquake, the robustness of the facilities requested by the CSAs must also take account of the risk of equipment leak which could jeopardise the water inventory in the pools of the reactor buildings and fuel storage. As a matter of fact, these situations can lead to a cliff-edge effect, considering in particular the possible significant decrease in the water inventory, the induced limited time before the fuel assemblies are uncovered and the particular related constraints on the operational management of accidents. In this respect, IRSN emphasises that, for reactors in operation or under construction, mitigating the consequences of a severe accident in a spent fuel pool would be very difficult. As part of the CSAs, IRSN considers that pipe inspections and modifications to the SSCs should be implemented to prevent the uncovery of fuel assemblies in an accident situation in which a leak would damage the equipment constituting the pools and its connected systems.

Concerning PWR severe accident management, EDF:

- described the situations considered in the present safety demonstration (risks considered, existing countermeasures or countermeasures being implemented),
- assessed the robustness of the reactors in operation for the severe accident situations considered (large-dimension containments, presence of hydrogen recombiners, filtration-venting system for reactors in operation, etc.),
- proposed additional provisions for the prevention or limitation of the consequences of a severe accident that would be induced by one of the extreme scenarios addressed in the CSAs,
- proposed that additional studies be carried out to better understand certain risks or evaluate the robustness of certain items of equipment beyond their design basis assumptions.

The IRSN points out that the provisions implemented so far at the reactors in operation or incorporated into the design of the EPR reactor are the result of the work achieved since the Three Mile Island accident. IRSN also recalls that the limitation of radioactive releases to the environment for any accident (with or without core meltdown) is a major objective in the continuous process of safety improvement in facilities. In France, this process is organised, in particular, around the ten-yearly reviews to periodically increase the safety requirements.

As part of the CSAs, EDF examined situations for which the main safeguard systems would be in a long-lasting fault condition and the main issue becomes limiting releases outside facilities and managing the site in an "uncertain situation" (due to the initial hazard and potentially degraded radiological conditions). IRSN emphasised the relevance of improvement proposals made by EDF for extreme situations; these proposals remain, however, to be consolidated. IRSN also formulated additional requests concerning, in particular:

- the identification of dreaded scenarios for the facility in shutdown states,
- the equipment used to limit the consequences of a core meltdown accident in these situations,
- the anticipation of certain modifications planned during the ten-yearly reviews of reactors in operation,
- the reinforcement of measures (human and material resources) for the management of these extreme situations in all the reactors of one site, including if the radiological situation is degraded.

These measures to prevent significant releases into the environment in the situations postulated in the CSAs will be robust for beyond design hazard levels. Generally speaking, IRSN believes that all EDF proposals, supplemented by IRSN's recommendations regarding the management of a severe accident, will significantly enhance the safety level of existing facilities.

In conclusion, IRSN believes that EDF's proposals in the scope of incorporating the measures for preventing core meltdown and limiting releases into the environment into the "CSA hardened safety core" completed by IRSN recommendations will significantly contribute to increasing safety performance. The adequacy, precise definition and planning of the provisions thus foreseen will have to be addressed in future exchanges with EDF to ensure that they will provide the robustness expected and within time frames commensurate with the safety implications. IRSN considers it appropriate, in the light of experience feedback from the Fukushima accident, to discuss the integration of these situations into the safety demonstration.

EPR Reactor

The EPR reactor has benefited, since its design, from additional measures compared to reactors in operation for the prevention of situations involving total loss of heat sinks (main heat sink and diversified heat sink) and electrical power supplies (6 backup diesel generator sets compared to 2 in the nuclear reactors in operation) as well as for the management of a severe accident. It is also better protected against external hazards such as earthquakes (common basemat for the nuclear island, for example) and flooding (location of platform taking into account changes expected in sea level up to 2080). Nevertheless, EDF proposed specific improvements to the design of this reactor to limit the risk of accident in the event of extreme situations and to define a "hardened safety core" in the same way as for reactors in operation.

HFR (ILL)

The Laue-Langevin research institute (ILL) believes that the generalised loss of electrical power supplies combined with a loss of the heat sink cannot lead in the short term to dreaded situations (BORAX-type reactivity accident or in-air melting of the in-pile fuel element), considering that the available length of time to take action is at least about 4 or 5 days. The analysis performed by the ILL leads to consider that only the scenarios involving a break in the reactor coolant system, a rupture in the experimental channels or a loss of leaktightness in the storage channel will initiate dreaded situations.

Presently, the facility does not seem to be correctly protected for design basis earthquakes as regards in-air melting risk in the reactor. Furthermore, in its current configuration, the system implemented to limit releases into the environment in this situation also presents weaknesses for this level of earthquake. Finally, in the event of dam rupture caused by an earthquake, the facility's fallback position would be under water and the electrical supply would be lost; monitoring and control of active mitigation systems would be inoperative. Control of the accident situation would become a difficult issue.

Following its analysis, the ILL has undertaken not to restart the reactor after the winter 2011-2012 shutdown until reinforcements to improve the management of these situations have been completed. Additionally, so as to enhance the robustness of the facility to extreme natural hazards, the ILL presented an improvement programme to be implemented by 2014 to increase its capacity to manage a severe accident and to improve the robustness of the facility faced to an earthquake combined with flooding corresponding to a cumulative rupture of four dams located on the Drac.

CEA FACILITIES

As regards the Phenix plant in Marcoule, the major risks are linked in particular to the presence of sodium liable to lead to fires releasing toxic aerosols (sodium-air reaction) or sodium-water reactions releasing hydrogen. Since it is difficult to envisage limiting the consequences of large-scale sodium-water reactions, this risk must be prevented. As a consequence, the CEA has undertaken to analyse, in more detail, the behaviour of mechanical equipment with the weakest margins in the event of an earthquake. Moreover, for the flood risk, the CEA has undertaken to present the protection measures adopted for the sensitive rooms of the facility, as well as the associated implementation schedule. Concerning risks related to sodium, the CEA plans to use additional means of sodium fire extinction which have to be defined more precisely.

Concerning the CEA-Saclay OSIRIS reactor, the CEA believes that in the event of a generalised loss of electrical power supplies and water makeup system, the grace period before risk of core meltdown is very long (several dozens of days) and allows water injection from a source outside the facility. Regarding seismic risk, the CEA identified improvements to reinforce the aforementioned grace period. Flood risk is not likely to affect the items of equipment which are essential to manage these situations.

The CSA of the CEA-Cadarache Jules Horowitz Reactor (RJH), which is currently under construction, takes into account the latest developments of the facility. The dreaded situations identified by the CEA include fuel assembly melting in air and melting in water, combined with containment damage leading to radiological impact. The CEA postulates that the dreaded situations would be initiated by a loss in the core or pool cooling systems. IRSN believes that CEA's proposals to have a water reserve inside the facility, as well as to extend the operating range of the water recirculation system must be implemented. At this stage, IRSN points out that the CEA has not defined the equipment to be developed in the "short term" phase of the accident and which will constitute the "hardened safety core". Concerning seismic risk, the CEA agrees to evaluate the robustness of the reactor block and the reactor coolant system, which is satisfactory. Finally, the CEA has presented the measures selected to manage a severe core meltdown accident.

The core of the CEA-Cadarache MASURCA reactor was removed in 2007; fissile materials are currently located in the storage and handling building (BSM). Considering the current facility condition, the main risk identified by the CEA is a partial or total collapse of the BSM after an earthquake. Considering the earthquake level for which the BSM integrity would no longer be ensured, the CEA decided to build another building (expected end of 2017) and to transfer temporarily the fissile materials in another building. Until this transfer, the CEA has agreed to implement corrective measures to limit the dissemination of materials in the event of an earthquake, as well as criticality risks.

The CEA-Cadarache plutonium technology facility (ATPu), shut down since 2003, is being dismantled. However, the ATPu does not withstand the design basis earthquake of the site. Seeing that the facility is under dismantling, the CEA considers that seismic reinforcement is not foreseeable. Therefore, IRSN believes that the reduction of the remaining plutonium is the first measure to be implemented to limit the consequences of the building's destruction. At the request of IRSN, the CEA has committed itself in a number of actions concerning the monitoring of materials still present in the facility, identification of the most sensitive rooms in terms of dissemination, criticality and fire risks in the event of an earthquake, as well as the means likely to reduce the consequences for the environment.

AREVA LABORATORIES AND PLANTS

Even if AREVA's behaviour raises some concerns, in particular as regards the number of configurations studied and the identification - based essentially on the opinion of the engineer - of different levels of hazards leading to the loss of safety functions, AREVA proposes structural and organisational improvements for the sites, which should over time increase the robustness of the facilities and the emergency management resources. Consequently, IRSN thinks that AREVA's methodology, focused on the analysis of dreaded situations leading to significant consequences in the short term, constitutes a satisfactory first step in the integration of operating feedback from the Fukushima accident. However, a broader analysis taking account of the recommendations detailed below seems necessary to IRSN for the support of studies on emergency management that AREVA has undertaken to perform by mid-2012:

- for all facilities:

- extension of the study to other dreaded situations and to the associated key SSCs and "CSA hardened safety core",
- consideration of aggravating factors (fire, explosion, criticality accident, etc.) in the analysis, with integration of the failure of measures intended to prevent them,
- analysis of the adequacy and of the robustness of facility diagnostic means (process and facility condition before and after hazards), means of detecting an event or an over-accident and means for limitating the consequences,
- analysis of the feasibility of actions for limitating the consequences, considering in particular the condition of the site, induced events and facilities classified for the protection of the environment located on or in the vicinity of the site;

- for the La Hague site: reinforcement of robustness in water supply and capacity to restore the emergency cooling system for spent fuel pools (C, D, E and NPH) and storage tanks of concentrated fission product solutions;
- for the Melox plant: evaluation of the robustness of the key SSCs of the "CSA hardened safety core" by considering a post-earthquake fire and taking into consideration the loss or deterioration of the HD exhaust system (including the last level of filtration);
- for the FBFC facility: implementation of a system to limit the consequences of a hydrofluoric acid leak (automatic spraying);
- for the Tricastin site:
  - examination of flooding risk of Structure 200, in addition to the study of the seismic behaviour to be carried out by AREVA,
  - improvement of the "uranium hexafluoride (UF_6) emission" zone and of HF storage tanks of the W plant, in particular with respect to external hazard risks (SSSE, flooding, explosion, etc.);

  in the meantime, mitigating measures will have to be implemented to limit the quantity of UF_6 liable to be dispersed and decrease the radiotoxic plume without local human intervention.

7. CAPACITY OF THE LICENSEES TO MANAGE AN EMERGENCY SITUATION IN THESE CONDITIONS

IRSN believes that abandoning a nuclear site further to an accident, which would let the facilities out of control, is not conceivable. To be considered "robust", emergency organisation and means must remain operational for hazard levels far above those taken into account for facility design. Furthermore, IRSN thinks that these means must be highly capable of adapting to situations that have not been foreseen up to now. In its assessment, IRSN verified in particular the capacity of the last level of defence-in-depth to withstand any circumstances. IRSN has made sure to check that the licensees had clearly identified the main areas for improvement as well as the necessary action plans for developing "robust" emergency organisation and means.

At this stage, IRSN does not have all of the elements for the assessment of the "robustness" of the emergency organisation and means provided by the licensees. However, according to IRSN's assessment, the action plans proposed by EDF and AREVA must be completed. During the course of the investigation, EDF and AREVA agreed to pursue the actions in progress and to complete them. The CEA reports indicate that the robustness of its emergency organisation and means will be analysed within the framework of the site studies scheduled for 2012. In view of the lack of sufficient technical elements emphasised by IRSN, the CEA agreed to provide what is expected.

Finally, IRSN considers that the project for improvement proposed by the ILL and completed during the examination to satisfy the requests of the institute is globally satisfactory.

As concerns human interventions in accident situations, the files submitted by the licensees provide little information. In this context, IRSN's approach consists in identifying, within the considered scenarios and associated countermeasures, what either entails particular organisational dimensions or is related to human actions. IRSN believes that anticipating these problematic situations must enhance feasibility and efficiency of human action, while considering the health and safety of the persons involved in such situations.

8. SUBCONTRACTING

Using subcontracting which is a component of the licensee's industrial policy is a complex subject with multiple regulatory, socio-economic and socio-technical constraints which raises societal issues. IRSN's assessment was to evaluate the real impacts of using subcontracting on the safety of facilities and the radiation protection of workers, and examining the relevance of the measures implemented by the licensees to organise and control the work of subcontractors. IRSN believes that the examination of the files submitted for the CSAs is only a first step and that identifying the nature and magnitude of the effects of subcontracting on the safety and radiation protection constitutes a serious issue requiring additional investigation.

9. CONCLUSION

The complementary assessments **focused on the major weak points of the facilities** which will have to be addressed as quickly as possible. In this respect, IRSN emphasises that the elements and demonstrations deemed admissible and acceptable at this stage may require further more in depth analyses.

IRSN also believes that its **objective consists first in identifying the main elements contributing to the robustness of the facilities (with regard to situations considered in ASN's specifications) and then in defining the priorities in terms of modifications or required analyses**; this is accomplished notably by determining scenarios or phenomena liable to lead to dreaded situations, for the extreme situations specified in ASN's specifications.

Eight months after the Fukushima disaster, the complementary safety assessments, although carried out within extremely tight deadlines, allowed:

- evaluating facility compliance with applicable safety requirements for external hazards such as earthquakes, flooding as well as loss of cooling and energy, and identifying a number of priority corrective actions; for facilities addressed in a CSA in 2011, this analysis will be completed by the end of 2012;
- defining an innovative approach - independent from the usual safety approach (safety reviews) – with the intention to reinforce the existing safety measures and providing better robustness to enable facilities to deal with situations that have not been considered so far in the safety demonstration and which are liable to generate cliff-edge effects. This approach led to the definition of a "hardened safety core" ensuring the protection of the structures, systems and components playing an essential role in the control of safety functions even in the event of a hazard well beyond the design bases;
- identifying limits in the current safety demonstration that will have to be reviewed in the near future, before the ten-yearly reviews (rules used for determining seismic and flood hazard level, fire protection,

external hazards and combination of hazards to be considered, assumptions used for defining measures for the management of loss of cooling or electrical power supply, etc.).

In view of the exchanges also held in the context of the periodic safety reviews as well as, for PWRs, within the framework of discussions on the extension of the facility operating period beyond 40 years, the licensees have been able to propose practical improvements for their own facilities which, from IRSN's point of view, will significantly improve the safety of French nuclear facilities.

IRSN acknowledges the quality of the analyses performed by the licensees within very short deadlines, which have led to a number of findings and practical proposals.