



Implications of the Fukushima accident for SNETP

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1. Introduction:

The accident which occurred at the Fukushima Dai-ichi nuclear power plant on March 11, 2011, has raised public concern on nuclear energy and drew a new attention to the safety of nuclear power plants, in particular in case of extremely severe external hazards.

A number of initiatives have been undertaken in many countries and at international level in order to take into account the very first lessons learned from this accident for the improvement of nuclear reactors design and for the improvement of the organization to manage an accidental situation. It can be quoted the OECD/NEA ministerial seminar on June 7th, the safety authorities' forum on June 8th and the ministerial conference organized by the IAEA which resulted in the Action Plan on Nuclear Safety approved by the Board of Governor and endorsed by the IAEA general conference.

Most of the countries operating nuclear reactors have launched systematic reassessment of the safety margins of their nuclear fleet under severe natural hazards – reassessment usually called stress-tests. A comprehensive stress tests process has been launched by the European Council under the European Commission coordination.

SNETP¹ gives nuclear safety the highest priority in its vision and Strategic Research Agenda. European technical safety organizations (TSO's) are involved in the activities of the platform governance and working groups. SNETP promotes safety related research and harmonization at European level, for current and future generation of nuclear fission technologies. This is the reason why the SNETP Governing Board decided to empowered a Task Group to investigate how the first lessons learned from Fukushima accident could impact safety related R&D orientations and priorities.

In its investigations, the Task Group has concentrated on medium and long term R&D, in particular on the developments, updating and validation of methods and tools for areas which are not considered as enough understand.

The report issued by the Task Group gives high level orientations that will be more detailed by SNETP Technology Task Groups (GENII/GENIII, Cogeneration, and ESNII). This report will be updated as necessary with the outcomes of the European stress-

¹ SNETP (the Sustainable Nuclear Energy Technology Platform) is a European technology platform established in 2007. It gathers more than 100 stakeholders coming from Industry, research , Safety organizations, Universities and nongovernmental organizations dedicated to promote research, development and demonstration of nuclear fission technologies necessary to achieve Europe's strategic technology plan (SET Plan) goals.

tests for which a final report from the European Commission is expected by June 2012.

On a longer term – several years – the outcomes of the future expertise acquired on the four reactors and fuel pools of Fukushima Dai-ichi site will be very valuable for the qualification and validation of the results of the R&D tasks.

This report shall be thus considered as a very first step of the process but it already catches very important features which are summarized in the here-below document.

2. What are the main challenges revealed by the Fukushima accident?

The Fukushima accident was triggered by the combination of two main initiating events:

- An exceptional magnitude earthquake which caused the sudden total loss of almost all the off-site power supply. The reactors 1-2-3 which were in operation have been automatically shut-down. The residual heat removal systems were started immediately after, relying on electricity supplied by emergency power sources (diesel generators and batteries).
- The associated tsunami has caused the flooding of the site under a wave about twice the size considered previously in the risk evaluation. It led to both the loss of all the emergency power supply systems and of the cold sink.

The immediate challenge for the emergency response team was to recover cooling capabilities (at the beginning of the event, 5 to 10 MW were needed to be removed per reactor which required 5 to 10 m³/h of water to each reactor) in a situation where the off-site power supply has required about 11 days to be effective. The main issue is now to assure a long term reliable cooling of all the units on site, i.e. maintaining a suitable close cycle cooling capability.

This situation has affected all the 4 reactors in operation or loaded with fuel and the spent fuel pools. A detailed analysis of the system deficiencies which caused the loss of emergency cooling systems is still difficult to perform due to the lacking information but nevertheless and accordingly with the current knowledge of the accident, the efficiency and the reliability of the decision making process during this extreme event were clearly not optimal.

The challenges identified from the first lessons learned from the accident are the following:

- To extend even more in-depth the safety approach to any type of initiating event, especially severe natural hazards and any combinations of them. It shall be done for current reactors, GEN III reactors and the development of GEN IV reactors.

- To include more systematically at the design stage the beyond design basis accidents to assure the robustness of the defense in-depth and to avoid cliff edge effects. The approach shall include situations where all units on the same site are affected by a beyond design event.
- To develop wider and more robust lines of defense with respect to design basis aggressions and beyond design basis events to define additional measures to consider in the design.

A specific emphasis has to be put on the emergency management which has been very challenged during the accident due to:

- The concomitance of many events, the severe environmental conditions and the mutual interaction between the affected units on site.
- The complexity and the difficulty of the decision making process which has altered the effectiveness and the promptness of the actions and which has generated both confusion and delays.
- The practical impossibility to recover a suitable and stable electrical supply source during several days.

The improvement of the emergency preparedness and response shall include the consideration of several items:

- The availability of more sophisticated tools to provide to the operators more reliable and quick indications/measurements on the reactor status to help in the implementation of an appropriate recovery strategy.
- The availability of redundant intervention means in the vicinity of the site.
- A better international cooperation/expertise which could provide help on the plant status diagnostic, on the prognostic for the situation evolution and on the mitigation strategy.

Safety related R&D is already included in the main orientations of the SNETP Strategic Research Agenda and, in particular for the current reactors, proposes specific tasks related to the long term operation and to severe accident phenomenology. The R&D effort is largely shared through EURATOM framework program and, at international level, through the OECD/NEA programs. The R&D on severe accidents has in particular the objective to produce knowledge, methods and codes to assess risks for all beyond design situations.

A careful investigation of the Fukushima accident outcomes will generate a new scale of priorities with a specific focus on extreme external events and their combinations, on common mode failures and on human behavior and with the assessment of their impact on the robustness of the defense in depth.

3. Identification of relevant research areas:

Following a review of the available information on the Fukushima accident, the Task Group has identified 9 main areas of research, focused on siting, design and operation of nuclear power plants. A special attention shall be made on how the research outcomes will be implemented and so transferred into normal industrial practice.

Fukushima event reveals especially the importance to enhance the analysis of human and organizational factors under high stress and harmful conditions in order to identify operational way to improve the emergency preparedness and the response to a severe nuclear accident.

a. Systematic assessment of vulnerabilities in the defense in depth:

The main objective is to develop a systematic approach for the determination of safety margins and the risk of occurrence of cliff-edge effects for extreme events beyond the design basis.

The methodologies shall include the identification of extreme and rare events potentially leading to common mode failures of multiple plants system, their consequences and the effects of interrelation between plant systems and operators actions. The R&D tasks shall also include the development of complex models for the behavior of nuclear power plants under extreme loads beyond the design basis and the determination of the ultimate capacity of physical barriers and of the integrity of the reactor containment.

b. Advanced method for the assessment of external hazards:

The focus of this item is to enhance and to harmonize the methodologies for the assessment of external hazards and for the combination of them as well as their effects on nuclear power stations.

The methodologies shall be updated on the basis of the state of art knowledge in earth science and shall consider man-made hazards (airplane crash, missile impacts, cyber-attacks, malevolent acts).

c. Probabilistic safety assessment (PSA) applications to extreme external hazards:

To complement the deterministic approach, PSA are performed with a systematic approach making use of realistic assessments of the performance of equipments and operators. PSA has the potential to provide a deep understanding of the inherent risk of operating the nuclear power plant over a much wider range of conditions.

The main objective is to extend the present PSA methodologies to extreme events with a very low frequency. It shall take also in consideration the availability of site infrastructures, the prolonged station black-out and the potential loss of ultimate heat sink which are "traditionally" out of the scope of PSA. This type of analysis shall consider also human reliability and behavior under such circumstances.

d. Advanced method for the analysis of severe accidents:

The main objective is to review the state of the art and to develop and validate robust models and simulation platforms for the analysis of severe accident.

Typically this area is mainly the continuation of already on-going research programs but with a need to focus on phenomena which are not adequately understood for post accidental heat removal, coolability of overheated and partially relocated reactor core, in-vessel core melt progression, in-vessel molten corium retention, corium stabilization in containment, molten-core-concrete-interaction and hydrogen generation and behavior in the containment.

e. Enhanced methods for accident management:

In complement to the improvement of the organization aspects, the main objective is to enhance overall the level of knowledge, skills, predictive tools and strategies applicable for accident management. The new feature is a special emphasis on particularly severe accident (long term loss of electricity supply, loss of heat sink).

The tasks include investigations on reliable monitoring and communication tools under harsh severe conditions, consideration of human behavior and organizational factors in decision making in such circumstances.

f. Improved modeling of fuel degradation in spent fuel pool:

It has been very difficult to understand the events occurring on spent fuel pool of reactor 4 (fires, hydrogen deflagration). The main objective is to improve the knowledge of the fuel degradation phenomena and failure modes for fuel assembly stored in the spent fuel pools and to develop and validate modeling tools.

The R&D actions shall consider the scenarios of the dry out of the pool and the following reflooding phase including the effect of the possible presence of debris that may fallen into the pool.

g. Radiological impact of serious reactor accidents:

It is the continuation of existing R&D programs in order to update and validate models determination of the source term, for the dissemination of radioactive substances and radiological impact of the releases on the human health and on the environment. It includes the harmonization of the intervention levels for radiological

accidents and reconsideration of the INES scale as a tool for communication with the public.

h. Advanced safety systems:

The Fukushima accident and in particular the long term duration of the loss of electricity supply highlighted the potential interest in passive systems or more generally the design of safety related equipment and components based on passive rules. The main objective is thus to consider the capability of advanced passive safety systems for residual heat removal for extreme accident scenarios (prolonged station black-out, loss of infrastructures, loss of instrumentation, and reduced accessibility to the plant).

Research in this field shall also address the development and the qualification of numerical tools for the 3D simulation of phenomena like multiphase natural circulation and heat exchange which is still a challenge for getting reliable results.

i. Advanced materials for nuclear reactors:

SNETP supports already a comprehensive R&D programs on advanced material for nuclear energy which is performed under the umbrella of the European Energy Research Association (EERA). The main objective is to develop, to test and to model the behavior of new and existing structural material for nuclear components, taking into account the key severe conditions (corrosive environment, high radiation dose exposure, and high frequency thermal and mechanical fatigue).

In addition, efforts should be devoted to support the development of internationally harmonized methodologies. Larger reliance on the European standardization system should be encouraged. Also for GEN IV reactors, the joint development of codes and standards should provide a common European tool for capitalizing on the knowledge issued from the R&D on advanced materials and manufacturing processes.

4. Conclusions:

Despite Fukushima accident, the nuclear energy remains an important component for today and for the future European energy mix and also be a very significant contribution to fulfill the worldwide energy needs. But, it is the prime responsibility of the nuclear energy stakeholders – and SNETP is an appropriate forum – to take benefit of all the lessons learned from the Fukushima accident.

Research and development are essential tools for a better understanding of the phenomena and, thus, to enhance the prevention and the mitigation of the severe accident. No really new phenomena were revealed from the Fukushima accident and the basic orientations of the Strategic Research Agenda are still valid. However the specific research areas identified in this document shall be considered with the appropriate priority in the update of the Strategic Research Agenda to be developed by the end of 2012. In particular, the issues related to extreme severe and rare accidents shall be considered in a more global approach to safety in order to better understand the design margins and the behavior of nuclear reactors under beyond design basis scenarios.

Considering the current reactors under operation, the life time extension is still a relevant issue but it shall be associated with a comprehensive safety assessment in compliance with the highest safety standards.

With the perspective of the worldwide development of nuclear energy, the implementation of Generation III reactors should be accelerated and, with a longer perspective, the development of Generation IV reactors remains an important goal keeping high safety level at utmost priority.