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COMMON POSITION ADDRESSING FUKUSHIMA-RELATED ISSUES

Participation

Countries involved in the MDEP working group discussions:	Finland, France, India, People's Republic of China, Sweden, the U.K. and the U.S.
Countries which support the present common position:	Finland, France, India, People's Republic of China, Sweden, the U.K. and the U.S.
Countries with no objection:	
Countries which disagree:	

Multi-National Design Evaluation Programme

EPR Working Group

COMMON POSITION ADDRESSING FUKUSHIMA-RELATED ISSUES

Introduction:

The MDEP EPR Working Group (EPRWG) members, referred to herein as “regulators”, consist of members from the United States, the United Kingdom, France, Finland, China, India and Sweden. Because not all of these countries have completed the regulatory review of their EPR applications yet, this paper identifies common preliminary approaches to address potential safety improvements for EPR plants, as well as common general expectations for new nuclear power plants, as related to lessons learned from the Fukushima Daiichi accident or Fukushima-related issues.

After the safety reviews of the EPR design applications that are currently in review are completed, the regulators will update this paper to reflect their safety conclusions regarding the EPR design and how the design could be enhanced to address Fukushima-related issues. The common preliminary approaches are organised into five sections, namely, external hazards, reliability of safety functions, accidents with core melt, spent fuel pools, and emergency preparedness in design, supplemented by appendices related to areas where further studies were identified as necessary.

The appendices will be published before the end of 2014.

Context:

A severe accident involving several units took place in Japan at Fukushima Daiichi nuclear power plant (NPP) in March 2011. The immediate cause of the accident was an earthquake followed by a tsunami coupled with inadequate provisions against the consequences of such events in the design. Opportunities to improve protection against a realistic design basis tsunami were not taken.

As a consequence of the tsunami, safety equipment and the related safety functions were lost at the plant, leading to core damage in three units and subsequently to large radioactive releases (INES 7).

Several studies have already been performed to better understand the accident progression and detailed technical studies are still in progress in Japan and elsewhere. In the meantime, on-going studies on the behaviour of NPPs in very severe situations, similar to Fukushima, seek to identify potential vulnerabilities in plant design and operation; to suggest reasonably practicable upgrades; or to recommend enhanced regulatory requirements and guidance to address such situations. Likewise, agencies around the world that are responsible for regulating the design, construction and operation of EPR plants are engaged in similar activities.

Background information:

The Fukushima Daiichi accident demonstrates the importance of reinforcing the Defence-in-Depth principle, correctly identifying the external hazards, their magnitude, their credible combinations and the design provisions to protect the installation. This should be reflected in licensing requirements, detailed in the installation safety case and reviewed by an independent regulatory body. The accident also reinforced the need to have a comprehensive safety analysis using both deterministic and probabilistic methods in a complementary manner to provide a comprehensive coverage of all safety factors. In the safety assessment, specific consideration needs to be given to both multi-unit sites and to address long-term measures protecting the plant.

One has to bear in mind that the specific nature of individual events and challenges can never be completely taken into account in design and operation of a nuclear power plant (or indeed any other industrial facility). However, a robust design based on Defence-in-Depth with sizeable safety margins and diverse means for delivering critical safety functions as well as flexible, symptom-based operator response plans will help to address accidents beyond current design basis (i.e. latest licensing basis).

The design, construction, manufacturing and installation of structures, systems and components should rely on state of the art engineering measures and sufficient margin beyond the design criteria required for a design basis accident to avoid **cliff edge effects**[1]. Such an approach will help to ensure an appropriate response, should a beyond design basis accident occur. Provisions aiming at facilitating the repair/recovery of impaired safety functions should also be considered.

[1] **Cliff edge effects** are the effects of those hazards for which a minimal increase in the hazard's magnitude can have a much higher impact. For example, the external flooding hazard may have little to no impact to a nuclear power plant below a prescribed flood level. However, a small increase beyond that prescribed flooding level could impact many of the nuclear power plant's functions and lead to a severe accident.

Common Position:

EVOLUTIONARY IMPROVEMENTS IN SAFETY

I. The Fukushima Daiichi accident confirms the relevance of the general safety objectives that have been considered for Generation III reactors, such as the EPR (lower probability of core melt, limitation of releases, management of severe accident situations…).

As compared to most current operating reactors, the EPR reactor contains additional safety measures. For example, there are four redundant and independent trains of safety systems, including emergency diesel generator in each of the trains and additionally two diverse station black-out diesel generators. There are also systems to provide for severe accident management and protection against external events such as earthquakes and flooding. Total loss of main heat sink is also one of the design bases of the plant.

HAZARDS

II. While acknowledging that external hazards are primarily site dependent and that the adequacy of the design has to be reviewed on a case-by-case basis considering the site characteristics, to date regulators who have made safety findings in the review of their EPR design applications, find that the safety systems of the generic EPR are designed and protected to tolerate external and internal events, mostly by applying adequate physical separation and protection against dynamic loads.

The accident at Fukushima Daiichi has reinforced the need to undertake, as part of the safety review process for nuclear EPR power plant applications, a comprehensive analysis of external hazards, including consideration of relevant combination of events. The regulators believe this should be considered to include an analysis that addresses how these hazards could impact areas of the proposed NPP where significant amounts of radioactive material are expected to be present.

RELIABILITY OF SAFETY FUNCTIONS

III. It is observed to date, from those regulators who have made safety findings in the review of their EPR design applications, that since most EPR safety functions depend on electric power that the EPR reactors could suffer cliff-edge effects after a few hours following infrequent and severe external hazards, particularly those involving a common-cause failure that results in long-term loss of power and cooling. Those regulators acknowledge that safety improvements have been proposed to address those situations. Continued discussions, detailed design, and analysis will be needed to make final approvals of these improvements.

The key safety functions that should be protected are reactivity control, reactor and spent fuel pool cooling and confinement of radioactive material. Most safety functions of EPR depend on electrical power, hence high reliability of power supplies is essential. This high reliability is expected to be achieved through an adequate combination of redundancy and diversity.

Ensuring adequate protection of the power supplies against infrequent and severe external hazards is a lesson from the Fukushima Daiichi accident. Regarding emergency power supply, diverse, electrically adequately isolated power supplies need to be required as a part of Defence-in-Depth concept of the plant. Other actions for increasing the reliability of AC power supply at an EPR plant should be considered such as provisions of long-term fuel and lubricating oil reserves for all emergency power units at the site and ensuring the possibility of using mobile power supply units.

In spite of the reliability of the power supplies, as part of the Defence-in-Depth approach for EPR plants, a mitigation strategy for long term loss of electrical power is needed for all reactor states for an adequate length of time. Example of arrangements used in such strategies are enhanced capacity of some critical power sources, the possibility of providing sufficient electrical power through mobile means and/or the use of permanently installed power sources sufficiently independent and adequately protected from external and internal hazards, including infrequent and severe external hazards. The fail-safe status of safety related equipment in case of loss of power supply should be considered in the design taking into account possibly contradicting requirements.

The Defence-in-Depth approach needs to be applied also to the ultimate heat sink. The design of new nuclear power plants needs to provide diverse means to ensure reactor and spent fuel cooling. The use of a secondary ultimate cooling water system is an example of diverse means to provide reactor and spent fuel cooling for decay heat removal in case of unavailability of the primary ultimate heat sink. Other ways of achieving a Defence-in-Depth approach are by providing portable means to inject water into the steam generators, reactor coolant system, and make-up water into the spent fuel pool.

ACCIDENTS WITH CORE MELT

The Fukushima Daiichi accident confirms that potential accidents likely to lead to a core melt need to be considered in the design of EPR. Safety features which ensure the adequate integrity of the containment in case of an accident leading to a core melt need to be included in the design. These features need to have adequate independence from the other provisions of the plant and they should also be effective in case of external or internal hazards. Essential containment design principles related to the Fukushima accident deal with provisions to avoid over pressurisation (relying for example on containment venting and/or containment spray systems), hydrogen management and ultimate pressure strength in such accidents.

IV. The regulators recognise that the generic EPR design includes measures to mitigate the consequences of severe accidents. The EPR design benefits from reinforced measures to prevent accident situations such as high pressure core melt, global hydrogen detonations and in-vessel and ex-vessel steam explosions, which would lead to large or early releases. Nevertheless, as some severe accident management systems rely on AC and direct current (DC) power, at least after a few hours, regulators recognise the need to reinforce existing or proposed provisions to increase the time available before cliff-edge effect. Due consideration to those cliff edge effects is to be given while tailoring long term loss of electrical power mitigation strategies.

SPENT FUEL POOLS

The Fukushima Dai-chi accident also highlighted the need to fully consider safety in the design of spent fuel pools. This implies that single initiating events, multiple failure events, internal hazards as well as external hazards should be properly addressed. In particular, the structural integrity of the spent fuel pools needs to be ensured with adequate margin in case of external hazards.

Both the Defence-in-Depth approach and the prevention of accidents with early or large releases are fully applicable for fuel storage pools. Once spent fuel in a pool is overheated, it is very difficult to predict how the accident develops, when significant fuel melt starts to occur and how the molten fuel finally behaves. To achieve a safe outcome, it is essential to ensure the integrity of the spent fuel pools, and to maintain sufficient water level in the pools.

EMERGENCY PREPAREDNESS IN DESIGN

The accessibility and habitability of the control room, the emergency response centre, and the local control points (locations for necessary manual actions, sampling and possible repair works) need to be adequately protected against internal and external hazards. Suitably shielded and protected spaces to house necessary personnel in severe accident conditions should be considered for EPR plants.

In addition to the structures and fixed equipment ensuring the safety functions, the design of the reactor and the spent fuel pool should allow for the recovery of fundamental safety functions by mobile means in case of loss of safety functions in most of the reactor and spent fuel pool states. The implementation of these measures should be independent, as far as practicable, from non-mobile means, and the access to appropriate locations to implement these measures should be possible in due time.

The reliability and functionality of the on-site and off-site communication systems need to consider conditions relating to internal and external hazards.

Instrumentation and controls should be designed and installed in the reactor building and the spent fuel pools to survive accident conditions. The reliability and functionality of releases measurements, radiation level measurements and meteorological measurements may need to be strengthened. Assurance of the readiness to take samples and analyse them in a laboratory should be considered.

Severe environmental conditions and possible degradation of the regional infrastructure that may occur in a Fukushima-like accident may impact the emergency preparedness and should be considered in the emergency planning. On multi-unit sites, the plant should be considered as a whole in safety assessments and emergency management and interactions between different units need to be analysed. External events that may affect several units should be identified and included in the analysis. Events that may simultaneously affect several units should be explicitly considered in the emergency preparedness.

As these topics involve both design aspects and site-specific/licensee-specific provisions, the regulators are still evaluating the design and organisational provisions which are normally part of the arrangements for commissioning of the plant.

AREAS FOR FUTHER STUDIES BY EPRWG

Based on the issues explained above, the EPRWG decided to consider some areas in EPR design in greater depth to gain a better understanding on what are possible differences between different EPR evolutions (like Olkiluoto 3, Flamanville 3/Taishan 1, UK-EPR, US-EPR) in these particular areas of design and to highlight possible recommended practices.

In the June 2012 EPRWG's meeting, the following areas for further studies were identified:

- arrangements for long-term loss of electrical power (supplies and distribution systems) to ensure long term decay heat removal (appendix 1);
- reliability and qualification of severe accident management instrumentation (appendix 2);
- management of pressure in containment during severe accidents (appendix 3);
- long-term cooling of spent fuel pool; reliability of cooling and makeup water systems, instrumentation and hydrogen management (appendix 4);
- management of primary circuit residual heat removal and sub-criticality (appendix 5).

The appendices will be published as they are finalised by technical experts' subgroups in charge of them respectively, and before the end of 2014.

APPENDIX 1: LONG-TERM LOSS OF ELECTRICAL POWER

Purpose

To identify common positions among the regulators reviewing the EPR mitigation strategies for long-term loss of electrical power in order to:

1. Promote understanding of each country's regulatory decisions and basis for the decisions,

2. Enhance communication among the members and with external stakeholders,

3. Identify areas where harmonisation and convergence of regulations, standards, and guidance can be achieved or improved, and

4. Support standardisation of new reactor designs.

Definition

Long-Term Loss of Electrical Power (LTLEP) **-** A prolonged loss of all alternating current (AC) and/or direct current (DC) power sources in nuclear power plants which are used to help provide the safety functions of reactor core cooling, sub-criticality, containment, and spent fuel pool cooling.

Discussion

On March 11, 2011, the Fukushima Daiichi nuclear power plant experienced a large seismic event followed by a significant tsunami. The tsunami inundated many of the facilities at the plant, including many of the electrical power systems. As a result of the earthquake and tsunami, Fukushima Daiichi experienced a loss of all AC power for all units except Unit 6, which had one air-cooled diesel generator still available. DC power was lost at Units 1 and 2 due to the tsunami, and it was subsequently lost at Units 3 and 4 at a later time due to the inability to recharge the batteries. As a result of the LTLEP, core damage was experienced in Units 1, 2, and 3. The Unit 4 reactor core was off-loaded into the spent fuel pool, which maintained its integrity, and sufficient cooling was provided to the spent fuel pool due to the existing volume of water and water addition by emergency responders.

While nuclear power plants typically have redundant and multiple sources of electric power, the LTLEP at Fukushima Daiichi illustrates the consequences when a CCF of electrical power supplies occurs. Regulators around the world are currently looking at means to update requirements and guidance to ensure LTLEP conditions are sufficiently planned and mitigated. The Multinational Design Evaluation Program (MDEP) EPR Instrumentation and Control (I&C) Technical Expert Subgroup (TESG) has been charged with the task of evaluating common positions for the EPR new reactor design. The design is actively being reviewed in China, Finland, France, the United Kingdom, and the United States. Canada has also been a contributor to the MDEP EPR discussions.

Addressing requirements and guidance to address LTLEP requires expertise from various technical disciplines, expertise from regulators and the industry, and careful consideration of all aspects of plant safety. The common positions, recommendations, and comments are primarily applicable to the EPR new reactor design, but the information is also applicable to other new reactor designs, and to a lesser extent, operating reactors. Specific common positions for the EPR design are identified within this document.

New EPR Reactor Common Positions for LTLEP

I. *Defence against LTLEP should maintain the following key safety functions: (1) reactor core cooling, (2) reactivity control, (3) confinement of radioactive material, and (4) spent fuel pool cooling.*

In the event of an LTLEP, it is critical that decay heat from the reactor core be removed, the reactor remains sub-critical, containment integrity is maintained (including necessary heat removal and pressure reduction) in the event radiological material is released from the core, and the spent fuel pool continues to be cooled. The highest priority will be reactor cooling at the onset of an event since containment is not critical so long as fuel clad and reactor coolant system integrity is maintained. Spent fuel pool cooling will not become critical for several hours after initiation of an LTLEP due to the volume of water in the pool (provided spent fuel pool structural integrity is maintained).

II. *New reactor designs should incorporate multiple layers of defence-in-depth to protect against an LTLEP for all modes of operation. Layers of defence against an LTLEP will typically involve robust, permanently-installed equipment, robust and separately located mobile equipment, and adequately trained personnel and resources to implement the layers of defence in a timely manner. New reactor designs should have an assessment of the levels of defence-in-depth for an LTLEP. Such an assessment should consider (1) permanent and mobile equipment relied upon, (2) protection of such equipment against external and internal events, (3) capability of the equipment to provide key safety functions, (4) capability of personnel to utilise the equipment in the time required, and (5) transition to other layers of defence when one layer of defence is not available.*

An LTLEP may be a result of an external or internal event, whose cause, duration, and extent may be difficult to predict and measure. It is important for new reactor designs to incorporate, to the extent practical, design features and procedural actions to provide multiple layers of defence against an LTLEP. These provisions should address LTLEP common-cause failure sources such as flooding, failures of electrical switchgear, or fires. Design, planning, and preparation for an LTLEP will greatly assist responders in the unlikely occurrence of such an event. The value of planning and preparing for an LTLEP is for plant operators to consider factors that would affect their ability to maintain key safety functions. Response to an LTLEP will require a combination of installed plant features, procedures, knowledgeable plant personnel, additional equipment onsite and/or offsite, and offsite resources. It is important for plant operators to understand the capabilities of their equipment and personnel, means to access reliable plant status/information, required timing for actions, potential impediments to perform the actions, and how to coordinate multiple activities.

III. *The design of the plant against external and internal events is critical to protect against LTLEP.*

Proper siting and design of the nuclear power plants against external events such as earthquakes and floods will greatly improve their capability to avoid an LTLEP. As demonstrated by other nuclear power plants in Japan that experienced the same tsunami but did not experience an LTLEP, the siting, design, and construction of a facility greatly affects the outcome of such an external event. Similar conclusions can be drawn for internal events as well.

IV. Equipment that is used in the various layers of defence should be adequately protected and qualified against potential hazards and events, including provisions for sufficient testing and maintenance.

Various hazards and events could disable multiple sources of electrical power such as flooding, fires, and explosions resulting from internal or external events. NPPs are designed to withstand such events but there remains a remote likelihood that such events could exceed the design of one or more safety systems within the plant. To protect equipment against events that are beyond the design basis of the plant, it is important to design and locate additional equipment such that a single event would not disable multiple layers of defence. Qualification should consist of in-depth design, testing, and operational follow-up to demonstrate the ability of the equipment to provide high confidence that they will operate effectively when required under design basis conditions. Equipment should at least be protected to the same degree as main line safety systems, but depending on strategy taken (types and location of equipment) additional protection may be necessary.

V. The LTLEP mitigation strategy (including layers of defence and protection of equipment) is dependent on generic design aspects as well as site dependent variables based on types of external events that may occur.

The mitigation strategy should be tailored to capability of the generic design coupled with site specific characteristics. For example, a plant located in a desert region and not near any large water sources is less likely to experience significant flooding as compared to a plant near a coast that has a history of tsunamis. However, the plant located in the desert may experience other events such as sandstorms or extreme heat that the coastal plant is not expected to encounter.

VI. New reactors should consider support capability that could assist the LTLEP mitigation strategy.

Support for personnel and equipment include access to plant areas, spare parts, and communication. For example, mitigation strategies should consider access through security doors, ability to obtain spare parts from storage systems that normally use electronic means of access and retrieval, and mobile means of communicating across the plant site as well as with external resources. Consideration for personnel protection should be included in the mitigation strategy.

VII. The balance of plant safety should be maintained when addressing LTLEP mitigation.

As mentioned earlier, NPPs are designed to withstand external and internal events that could lead to an LTLEP. The likelihood of a new reactor experiencing an LTLEP should be very low when compared to other events and hazards. Any mitigation strategies for LTLEP should be weighed against the mitigation of other events and hazards within the plant design to ensure that the balance of plant safety is not impacted by any design features, procedures, or training used to address LTLEP.

EPR Common Positions for LTLEP

I. To date, regulators who have made safety findings on LTLEP have found that the EPR design appropriately accounts for external and internal events to make the likelihood of an LTLEP extremely low.

The original design and current siting requirements of the EPR is robust against external events such as earthquakes, floods, and high winds, making the likelihood of an LTLEP from these events to be very low. The EPR design incorporates principles such as physical separation, barriers, and design margin to reduce the impact of internal events. Regulators and vendors and its customers have discussed the design capabilities of the EPR and additional design margin and features have been added to enhance the capability to mitigate Fukushima-like events.

II. To date, regulators that have made safety findings on LTLEP have found the approach of permanently installed and mobile means by the EPR design to address LTLEP to be acceptable. Continued discussions, detailed design, and analysis will be needed to make final approvals.

Regulators have reviewed the initial proposals by AREVA and its customers to address LTLEP for the EPR design. The proposals use permanently installed equipment and mobile means to provide multiple layers of defence against an LTLEP. Regulators will continue to review the proposals as licensing documentation, detailed design, equipment, and procedures are available. Regulators may require some changes to mitigating strategies.

APPENDIX 2: RELIABILITY AND QUALIFICATION OF SEVERE ACCIDENT MANAGEMENT INSTRUMENTATION

Text to be issued from the severe accidents and digital I&C technical experts' subgroups in 2014.

APPENDIX 3: PRESSURE MANAGEMENT OF CONTAINMENT DURING SEVERE ACCIDENTS

Text to be issued from the severe accidents technical experts' subgroup in 2014.

APPENDIX 4: LONG-TERM COOLING OF THE FUEL POOLS

Text to be issued from the named ad-hoc technical experts' subgroup in 2014.

APPENDIX 5:

MANAGEMENT OF PRIMARY CIRCUIT RESIDUAL HEAT REMOVAL AND SUB-CRITICALITY

Common Positions agreed on the EPR Reactor for the management of primary circuit residual heat removal and sub-criticality

Residual heat removal

In the context of this discussion, the scenario considered includes extensive loss of active safety systems, but does not include catastrophic failure of the major primary circuit pipework. It may include a small loss of coolant accident caused, for example, by failure of the reactor coolant pump seals or a break due to a small pipe connected to the reactor coolant system. Furthermore, the event is assumed to impact multiple units on the same site.

I. *Maintenance of adequate primary circuit inventory is a key safety function that needs to be ensured on the EPR following an extreme event such as occurred at Fukushima.*

Following a Fukushima-type event at the site of any EPR power plant, it is essential that decay heat from the reactor core should continue to be removed and that following a leak in the primary circuit, sufficient means remains available to ensure an adequate make-up capacity to the primary circuit.

II. *It is essential that a means (either installed or mobile) is provided on the EPR to ensure adequate cooling and inventory make-up to the primary circuit.*

There is a consensus amongst the regulators that at least one means needs to be provided to ensure adequate cooling and make-up in the EPR following the long-term loss of off-site power together with failure of the Emergency Diesel Generators (EDGs) and that it will be necessary to demonstrate that this means is functionally capable of achieving the key safety functions, even in case of severe and rare external hazards.

In the EPR design, there are potentially a number of options for ensuring adequate levels of cooling and inventory make-up of the primary circuit following the loss of off-site power together with failure of the EDGs. These include:

a. For Flamanville 3 EPR, EDF is setting up a so called “hardened safety core” of structures, systems and components that is needed to fulfill the three fundamental safety functions in case of long-term loss of off-site power or heat sink, potentially due to a rare and severe external hazards. To remove residual power from the RCS, provisions should be defined, on one hand to compensate the loss of water that may be due to a small break, on the other hand to cool the RCS. Therefore, the installed Low Head Safety Injection (LHSI) trains in Divisions 1 and 4 that are used to provide cooling and inventory make-up to the primary circuit are part of the hardened safety core. Water for the LHSI trains is provided by the In-containment Refueling Water Storage Tank (IRWST). When the RCS is pressurised, its power removal is provided by the emergency feed water system (EFWS), also included in the hardened safety core.

The ultimate heat sink function is provided by the Ultimate Cooling Water System (UCWS), with electrical power provided by the Ultimate Diesel Generators (UDGs). UCWS and UDGs are also included in the hardened safety core. Provisions have been added (fuel transfer from the EDGs fuel tanks to SBO fuel tanks, increase of batteries autonomy, possibility to fulfill EFWS tanks using water basin located above station level) to ensure plant autonomy until the arrival of the Emergency Nuclear-Response Force. The design of these systems is being reviewed to ensure that the designs are "hardened" against the effects of extreme external hazards; such as flooding and seismic events.

Similar features are under installation for the Chinese EPR. In Finland same key safety systems are also designed against the effects of extreme external hazards and provisions will be added to ensure plant autonomy.

b. Some designs are considering installation of additional diesel-driven Steam Generator (SG) feed water pumps to provide SG cooling of the primary circuit following total loss of all AC power. On the US version of the design, the pumps provide low pressure feed and so the SGs are blown down to enable SG feed flow to be established. In some designs the intention is to provide high-pressure diesel-driven feed pumps since this avoids the need for SG blow down in the short-term and in the long-term may avoid the need to provide a mobile means to inject borated water into the primary circuit.

c. In some countries, the Stand-Still Seal System is claimed to ensure that loss of coolant accidents do not occur at the Reactor Coolant Pump seals; avoiding the need for short-term inventory make-up. In others, additional means are provided to inject coolant into the primary circuit.

Sub-Criticality

III. Efficiency of the automatic scram of the reactor is a vital function that needs to be ensured on the EPR following an extreme event such as occurred at Fukushima.

It should be demonstrated that, in a postulated Fukushima-type event at the site of any EPR power plant, the automatic scram would be able to operate. Due consideration should be given to deformations of the fuel assemblies and/or control rods induced by an earthquake exceeding the design bases.

IV. Maintenance of adequate long-term control of sub-criticality is a key safety function that needs to be ensured on the EPR following an extreme event such as occurred at Fukushima.

Following every reactor trip, there is an eventual reduction in the shutdown margin of the reactor core due to the cool down of the reactor core (given the moderator density reactivity coefficient of the core) and the decay of xenon. In the event of a Fukushima-type event at the site of any EPR power plant, it is essential that sufficient shutdown reactivity margin is maintained, by appropriate use of borated water injection and/or reactor cool down.

V. *It is essential that a means (either installed or mobile) is provided on the EPR to ensure adequate long-term reactivity control.*

Although the specific choice of which options are implemented in a particular country will depend upon national requirements, there is a consensus amongst the regulators that at least one means needs to be provided to ensure the long-term control of reactivity on the EPR following the long-term loss of off-site power together with failure of the EDGs and that it will be necessary to demonstrate that this means is functionally capable of achieving the key safety function.

On the EPR design there are potentially a number of options for ensuring adequate long-term control of reactivity following the loss of off-site power together with failure of the EDGs. These are:

a. Using the “hardened safety core” already discussed above. The make-up water taken from the IRWST is borated and so provides a means of ensuring the long-term control of reactivity.

b. On the US version of the EPR, it is proposed to use fire protection pumps or mobile pumps to inject borated water directly into the primary circuit.