Following the Fukushima accident, the nuclear industry’s stakeholders have raised new concerns about safety, especially about the plants’ resistance to exceptional natural hazards. Many have learned more about nuclear, and have more technical questions – about what would happen in case of an exceptional external hazard, about the cooling chain, or about used fuel pools.

As early as the first week following the accident, safety authorities in all countries launched extensive programs of safety checks. The primary focus of these safety checks is to focus on exceptional external hazards, in the same way that resistance to internal hazards was the focus after the TMI and the Chernobyl accidents. At the same time, all utilities have started proactive safety analyses to start answering safety authorities and in anticipation of appropriate action plans. These action plans will probably encompass further safety studies, possibly plant upgrades, as well as changes in safety procedures. These will apply to both existing plants, as well as new builds.

With its wide presence worldwide, and engineering resources in all continents, AREVA has worked closely with utilities, supporting them in their safety assessments since the beginning of the accident. AREVA has defined a “Safety Alliance framework” to provide a structure for analyzing safety issues after Fukushima, and for assembling the solutions needed to address them. This framework is structured around three imperatives: resistance to major hazards, robustness of cooling capability, and prevention of environmental damage.

**Imperative 1: Resistance to major hazards**

In the extensive media coverage following Fukushima, it has been very clear to the general public that the origin of the accident was an earthquake and the ensuing tsunami, both of exceptional magnitude. Key stakeholders have asked questions about the resistance of the nuclear plants in their area should an exceptional earthquake or flooding occur. Moreover, they have asked questions about the resistance of their nuclear plants to any other external hazards of exceptional magnitude more specific to their location: extreme colds in Scandinavia, tornados in central U.S., or flooding related to dike rupture in Netherlands, or dam accidents in numerous countries.

On March 23, the Western European Nuclear Regulator Association (WENRA), comprised of the heads of nuclear regulatory bodies from 17 European countries, set up a task force to quickly provide an independent regulatory technical definition of a “targeted reassessment of the safety margins of nuclear power plants (NPPs) in light of the events which occurred in Fukushima.” That is to say, it must be verified that external hazards that could occur on the site have been correctly taken into account, and in addition that the level of protection against major hazards such as earthquake exceeding the design basis, flooding exceeding the design basis, a combination of both or other extreme condition has been assessed. The results of these safety checks may indicate the “need for additional safety provisions being technical or organizational (such as procedures, human resources, emergency response organization, use of external resources).”
Similarly, on March 23, the U.S. government issued a temporary instruction for conducting inspections at U.S. NPPs based on the event of a “one-two” punch (earthquake and tsunami) as happened in Japan.

Today, resistance to major hazards is determined by defining site conditions. For every plant, an in-depth, site-specific analysis takes into account all historical data to make sure the plant design duly takes into account these site conditions. The site analysis is performed at the very early stage of a project, even before plant design selection.

For seismic resistance for instance, site analysis translates into specific ground motion requirements, defined by the utilities, then approved by safety authorities. Ground motion requirements are calculated based on the energy deposition (Richter Scale value), the distance from the fault, and the type of soil upon which the plant is sited (for example, hard rock like granite or soft soil like compacted limestone).

Lessons learned from Fukushima show the necessity to confirm the specific site conditions for every plant:

• This includes seismic resistance of course, but for many sites, other major hazards are also relevant to look at. In its first report to the Finnish ministry about how nuclear power plants are prepared for exceptional natural phenomena (released on May 16) STUK, the nuclear safety authority in Finland, mentions that companies shall investigate how some of the plants’ systems would function during earthquakes that would be “more intense than any earthquake considered possible in Finland until now,” but also such sub-zero and high temperatures so unlikely that they have not previously been taken into consideration.
• These reassessments will, as the example from Finland shows, potentially take into account more stringent scenarios in terms of event magnitude.

Following the check of the site conditions, and potentially this requirement to plan for higher magnitudes, the second part of the safety check will be to verify that the reactor resists these reassessed conditions, and that there are enough margins available in the design basis. Based on its experience working with the U.S. NRC, the ASN in France, the NSSA in China, STUK in Finland, HSE in the UK, and many other major safety authorities, AREVA has developed unique expertise supporting customers in safety analysis to demonstrate NPP resistance to major external hazards. For example, AREVA is well equipped to conduct seismic analysis, including seismic margin reassessment and seismic Probabilistic Safety Assessment (PSA), the development of seismic input, the evaluation of plant systems and components, piping, supports, and I&C, as well as a recommendation for needed plant upgrades.

An important lesson learned from the Fukushima accident is that the assessment must encompass not only the resistance of the reactor and the nuclear steam supply system itself – in power or shutdown conditions – but also of reactor pools. Reactor pools are necessary to store and cool the fuel after discharge. Following safety checks, some utilities may need to harden their reactor pools. In addition, an obvious measure for risk reduction will be to lower the density, the inventory, and therefore the residual heat in the pool. This will be achieved through the transfer of part of the inventory – especially that which has recently been discharged – for recycling or interim storage. Recycling enables used fuel to be transported as early as one year after discharge (as opposed to about 5 years for the dry storage route depending on reactor core management). Recycling also enables reduction of the total inventory of used fuel, as well as providing safe and sustainable storage and disposal of ultimate waste. AREVA has been proactive in helping customers re-evaluate their used fuel policy and to empty their pools, taking into consideration regulatory, economic, and technical parameters. AREVA has the experience and proven solutions to support utilities in the implementation of their used fuel policy – including licensing support – whether it is for recycling, on-site interim dry storage, or central interim storage.

In the case of New Build projects, the EPR reactor has been designed to meet the latest generation standards of safety requirements, which include, in the case of resistance to major hazards, complex sequences and severe accident. The EPR reactor has been designed to meet site-specific regulatory seismic requirements. For example, the granite geology of Olkiluoto, Finland, requires a nuclear plant be able to withstand a peak ground acceleration of 0.10g, whereas some U.S. sites as well as the Koeberg site in South Africa request a plant withstand up to 0.30g. Several structural features, such as the unique large and thick concrete slab on which the main nuclear buildings are all located, allow for design basis margins.

Seismic margin assessments performed on the EPR reactor, even if further demonstrations can be completed site by site, as required, ensure that the EPR reactor could withstand peak ground acceleration up to around 0.50 - 0.60g without damage that would impair the operability of its safety systems.

Imperative 2: Robustness of the cooling chain

As a result of the wide media coverage of the Fukushima event, the general public knowledge about how nuclear plants work has increased significantly. In particular, they understand that when a nuclear reactor shuts down, there is still a need to continue to cool down the reactor, so as to evacuate the residual heat. They also are aware of the presence and role of the reactor pools, and the necessity to maintain the cooling function on these as well.

As mentioned previously, in the safety check process following Fukushima, utilities have to assess the resistance of their plants to extreme hazards. They have to demonstrate they will be able to reach a safe shutdown state. However, safety authorities may question, “Yes, but if,” or what would happen if the magnitude of the hazard exceeds even the worse-case scenario, challenging the safety provisions taken in the design and, in particular, to demonstrate that no “cliff-edge” effect has to be anticipated.

In that scenario, the plant robustness must be assessed, accounting for the possibility of damage to safety systems. It is important to assess if and how the design and post-accident procedures can allow restoring of the safety functions, if they are lost as a consequence of the initiating event.

Utilities may have to perform specific analysis to evaluate
the grace period for different scenarios and, if it is the case, implement specific plant upgrades to harden their cooling chain for both the reactor itself and the pool. This may include upgrading their existing emergency diesel generators (EDGs) beyond design conditions so they are less susceptible to harsh environmental conditions and are easier to repair after impairment of serviceability. AREVA can support utilities in these projects for their specific needs, backed by vast experience with more than 300 diesel systems worldwide.

Hardening the cooling chain may also involve additional protection of tank rooms (including pumps) against flooding, protection of air intake and exhaust openings against shockwaves, or separate encapsulated batteries for black start capability. Additional mobile means may also be needed, with potential plant upgrade to allow easy connectivity of these mobile means to the plant.

As part of the AREVA Safety Alliance initiative, AREVA offers a full range of safety analysis, plant upgrades and safety procedure solutions to increase the robustness of the cooling chain, in these worse-case scenario situations for the existing nuclear plant fleet.

For new build projects, the advanced EPR reactor features a particularly robust cooling chain, beginning with water inventories in case access to ultimate heat sink is lost. The reactor building houses an 1,800 m$^3$ in-reactor water storage tank (IRWST), and each of the four safeguard buildings reactor building houses a 400 m$^3$ emergency feedwater system tank backed by refilling capacities of several thousand cubic meters.

Secondly, to power cooling systems in case grid power is lost, there are several levels of back-up separate and protected buildings:

- Four EDGs and associated fuel supply powers each safeguard division for 72 hours.
- Two redundant and diverse station black-out diesel generators, of different technology and supplier than the EDGs can supply power for the duration needed in the site-specific safety assessment, for example, 24 hours for OL3 and FA3.

The durations mentioned here for both the EDG and the SBO diesel generators are country- and site-specific, and can be increased if the reliability of the grid is weak. These power sources and water reserves can feed four fully redundant cooling systems (also referred to as safety trains), which can cool the core either through the secondary or the primary loop.

Additionally, the cooling systems of the EPR reactor can cool down the reactor fuel pool, which is housed in a building protected by the airplane crash resistance shell. The fuel pool cooling system provides heat removal from the pool and is arranged in two separate and independent systems, with two pumps that operate in parallel in each system. The two systems are physically separated. In case of failure of the two main systems, the fuel pool cooling system also includes a third diverse cooling system.

The high resistance, redundancy and diversity of the EPR cooling systems prevent any cliff-edge effect in case of worst-case scenario, and offer a significant grace period for the operator to restore safety functions durably.

**Imperative 3: Prevention of environmental damage**

The last thing the general public has seen following the Fukushima accident has been of course the environmental damage: first the explosions linked to the hydrogen build-up, then daily uncertainties about possible containment breach and fuel damage. These developments have led to radioactive releases in the air and in the sea water, requiring some protection measures with evacuation of the population within a 20 km radius, and controls over the food chain. The total amount of radioactive release to the environment has prompted the re-assessment of the Fukushima accident to a provisional level 7 on the INES scale.

The objective of the safety check process in itself is for the utilities to demonstrate – through the resistance to major hazards and through the scenarios of robustness in case of hazards beyond design – that they can never face the loss of safety functions and reach a situation of extreme conditions. However, regardless of the low probability of such a sequence, the consequences are too severe not to be taken into account. A deterministic approach to assess these cases is taken by most Safety Authorities worldwide. By definition, they cannot be related to any event in particular, as this event should have been foreseen and prepared for.

As part of the Safety Alliance initiative, solutions can be provided to address specific points such as:

- **Safety upgrade:** the prevention of hydrogen build-up such as occurred in Fukushima. During severe accident situations in which the fuel becomes uncovered, hydrogen can be released inside reactor containment. Based on the principle of catalytic oxidation, AREVA has developed passive autocatalytic recombiners that reduce hydrogen concentration. They are tested under severe accident conditions, and can be installed on any design: PWR, VVR, PHWR, BWR. They have already been installed in 100 NPPs in 17 countries.

- **Safety upgrade:** the reduction of containment pressure using qualified venting systems. AREVA has developed a solution that prevents the containment from overpressurizing, preserving the barrier for the confinement of radioactivity, while purifying the gases discharged. They can be installed on PWR, BWR and PHWR designs, and have today more than 50 applications worldwide.

- **Safety procedure:** clear, easy-to-use severe accident management guidelines that will help stabilize the situation of the reactor while minimizing radioactive releases. AREVA has developed expertise in supporting the customer to develop a complete OSSA (operating strategies for severe accidents), which includes implementation of immediate actions, continuous assessment of plant conditions, identification of candidate strategies, and implementation and monitoring of plant response.
The EPR reactor features systems designed to cope with a severe accident in order to manage it with no risk of significant radioactive releases into the atmosphere or soil. Those systems allow the avoidance of any highly energetic event that could compromise the containment as well as management of a molten core. First of all, dedicated severe accident depressurization valves have been added to the primary loop to avoid the possibility of a high-pressure core melt. Second, the EPR design is equipped with 48 passive autocatalytic recombiners to prevent hydrogen explosion risk. Last but not least, to prevent any steam explosion risk in case of contact between molten core and water, the EPR reactor has a core catcher to safely retain and cool down the core. All those systems offer a grace period of several weeks to stabilize the situation and prevent environmental damage.

Conclusion: A framework to prepare, preserve and protect

With a global presence, AREVA maintains very close working relationships with virtually every nuclear utility in the world. These relationships, combined with safety experience as an operator of its own nuclear industrial facilities, give AREVA a perspective unique among industry suppliers. From their front-line vantage point, the company has quickly structured its Safety Alliance framework for analyzing and addressing safety issues following Fukushima. Expertise on all reactor designs and a depth of engineering and project management bench strength make the company well positioned to deploy a catalog of Safety Alliance solutions to help utilities to prepare, preserve and protect their fleets now and for years to come.

PHILIPPE KNOCHE - AREVA, Chief Operating Officer

Philippe Knoche is appointed Chief Operating Officer of AREVA since July 1, 2011. From January 2010 to June 2011, he was Senior Executive Vice-President Reactors & Services Business Group of AREVA. Before being nominated as Chief Operating Officer of AREVA NP in May 2009, he had been the Project Director for AREVA’s “first-of-a-kind” EPR reactor in Olkiluoto, Finland, from 2006 to 2009. Prior to this project-leading task, he served as Executive Vice President in charge of AREVA's treatment (reprocessing) business unit. From 2001 to 2004, Knoche was Senior Vice President in charge of strategy for the AREVA Group. Before joining AREVA in 2000, Knoche served as anti-dumping case handler in the European Commission, as well as in the corporate field. Knoche is graduated in material science.