Der schwere Störfall im japanischen Kernkraftwerk Fukushima Daiichi in Folge eines Tsunami zeigt weitreichende Folgen für die Kernenergiebranche und damit auch für AREVA als Anlagenhersteller – auch wenn das Unternehmen nicht der Lieferant dieser Reaktorblöcke ist. Vor dem Hintergrund der von der Internationalen Atomenergie-Agentur (IAEA) formulierten Forderungen und den verschärften Auflagen seitens der Behörden hat Areva für bestehende Anlagen ein „Safety Alliance"-Programm gestartet. Es beinhaltet ein umfassendes Konzept zur Sicherheitsüberprüfung und bei Bedarf auch Nachrüstung von Kernkraftwerken, um so deren Robustheit und damit auch Sicherheit zu erhöhen. Sowohl die aktuell in Finnland, Frankreich und China im Bau befindlichen 4 EPR™-Kraftwerke als auch die von Areva entwickelten oder mitentwickelten Reaktormodelle Kerena und Atmea1 gehören der neuesten Generation III+ an. Alle Modelle verfügen über redundante, diversitäre und zum Teil komplementäre (aktive und passive) Systeme, um Störfälle zu verhindern und zu beherrschen. Sollte es dennoch zu weitergehenden Unfällen kommen, sind die Reaktoren so ausgelegt, dass die Auswirkungen auch bei einem schweren Störfall auf die Anlage beschränkt bleiben.

The events in Fukushima as seen from a manufacturer's perspective

Uwe Stoll and Ulrich Waas, Erlangen/Germany

The severe accident in the Japanese nuclear power plant *Fukushima Daiichi* on March 11, 2011 in the aftermath of a tsunami has had far-reaching consequences for the nuclear industry and thus for the manufacturers of nuclear power plants: All over the world, questions are now arising concerning the safety of nuclear power plants. It is discussed which lessons can be learnt from the events in *Fukushima* to make nuclear power stations even safer. Although it is true that the reactor units in question belong to the oldest generation of nuclear power plants built in Japan, they are in some aspects comparable to reactors in Western industrial countries.

Even though the affected reactor units in Japan were not built by *Areva*, the group feels more than ever committed to further enhancing the safety in nuclear power plants. The Safety Alliance program has recently been launched in this context. This catalog of measures comprises a wide variety of products and solutions that allow nuclear power plant operators to make their plants fit for new requirements during operation and maintain this level of safety also in the future.

Sequence of events

Units 1 to 3 of the nuclear power plant *Fukushima Daiichi,* which had been running when the earthquake occurred, shut down successfully; the safety systems worked in spite of the beyond-design earthquake. It was only after the 13-meter-high tsunami (a height for which the power plant was not designed) hit the plant that the cooling chain and the emergency power supply system were disabled (*Figure 1*). The core could no longer be cooled, hydrogen was released resulting in explosions. Furthermore, a core melt occurred in 3 reactor units.

Results and recommendations of the IAEA

The *International Atomic Energy Agency (IAEA)* wants to learn from the events in *Fukushima.* The agency has thus given far-reaching recommendations intended to significantly improve nuclear safety on a global scale.

- Protection against all kinds of natural disasters

The tsunami risk was underestimated for several nuclear power plant sites in Japan. Authorities, plant manufacturers and operators should therefore adequately evaluate the risk of all natural disasters and implement appropriate risk prevention measures. These evaluations as well as the evaluation methodology should be reviewed and reconsidered regularly in the face of new information and experiences and a better understanding.

- Safety concept

A staggered safety concept, physical separation, diversity and redundancy requirements should be implemented for extreme events, particularly where there is a risk of common failure of safety features.

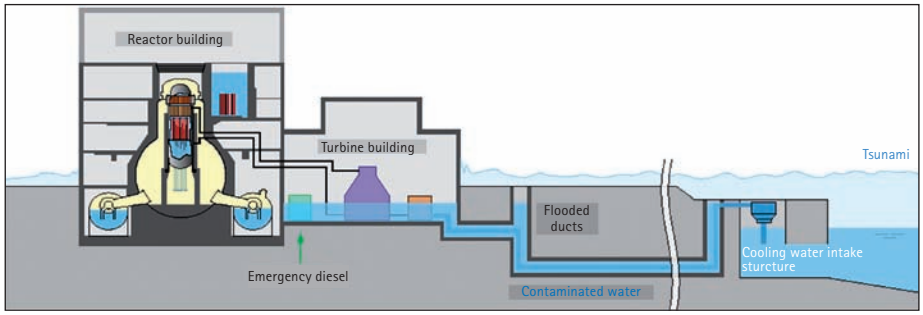

Fig. 1. Effects of the tsunami in the nuclear power plant Fukushima Daiichi.

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• Autonomy of authorities
Safety authorities should adequately account for extreme natural disasters in their requirements and regularly review these requirements. The autonomy of the authorities and the distribution of roles should in all cases satisfy the *IAEA* standards.
• Multiple external impact
Multiple external impact that occurs for a prolonged period of time should be adequately considered during design, operation and planning of emergency measures.
• Emergency response center
The accident in Japan has highlighted the importance of a protected emergency response center on the power plant site. This center should be equipped with reliable communication features, displays of essential plant parameters and the possibility to operate essential systems. Furthermore, sufficient maintenance resources should be stored there. Such centers should be provided at all nuclear plants that pose a potential risk. Moreover, simple and robust devices should be available that allow the basic safety functions to be restored in the shortest possible time.
• Hydrogen
The risks of hydrogen formation should be investigated in detail and the necessary steps to reduce it should be taken.
• Preparedness for emergencies
Emergency preparedness, especially in the early phase of an accident, should be designed and be appropriate for severe accidents.

The *IAEA* furthermore calls upon the nuclear community to "... take advantage of the unique opportunity created by the *Fukushima* accident to seek to learn and improve worldwide nuclear safety." As a plant manufacturer, *Areva* considers compliance with the *IAEA* requirements to be a major prerequisite for the safe operation of nuclear power plants – and along with that for public acceptance of nuclear energy.

Reactions to the accident in Germany and in the world

Although the German plants satisfied the major aspects of the *IAEA* requirements mentioned above, the reactor safety commission confirmed the robustness in its statement, and even though the life-span extension had been adopted in fall 2010, the population has lost much confidence in the aftermath of the accident in the nuclear power plant *Fukushima Daiichi*. Reason enough for German politicians to opt for an unequaled nuclear phase-out program shortly after the events in *Fukushima* – to immediately shut down 8 plants and to phase out nuclear energy earlier than planned by 2022 (*Figure 2*). Only Switzerland plans to prohibit the construction of new nuclear power plants but without limiting the life-span of the 5 existing plants. In a referendum in June 2011, Italy has decided against the planned revival of nuclear energy.

Fig. 2. German reactions to the events in Fukushima, Japan

Authorities in most other countries operating nuclear power plants have until now introduced short-term investigations and measures to come up with more detailed analyses and stress tests and any potential requirements resulting thereof (*Figure 3*). In the long term, some countries are deliberating about whether to tighten the regulations or measures to strengthen the safety authorities.

Consequences from a plant manufacturer's perspective

The accident in the nuclear power plant *Fukushima Daiichi* has raised questions for *Areva* as well, such as:

- Do design deficits exist for the group's plants?
- What is the remaining risk?

It is certain that the design deficits encountered in Japan do not exist in German nuclear power plants and that the German reactors possess an internationally renowned safety standard of conservative design and safety margins. This was also confirmed by the reactor safety commission.

German plants also offer the best protection worldwide against plane crashes in the context of terrorist attacks with a commercial aircraft as discussed in the public, because the possibility of this event was taken into consideration early in the design process: All plants that are still in service in Germany are protected against the crash of a phantom military plane; this provides considerable protection against the deliberate crashing of a commercial aircraft. Since the attacks on September 11, 2001 in the US, the supposed crash of a large

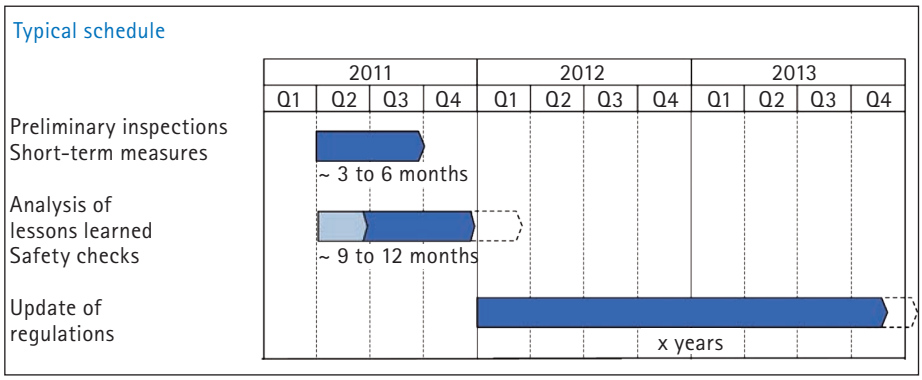

Fig. 3. Three types of measures from safety authorities worldwide.

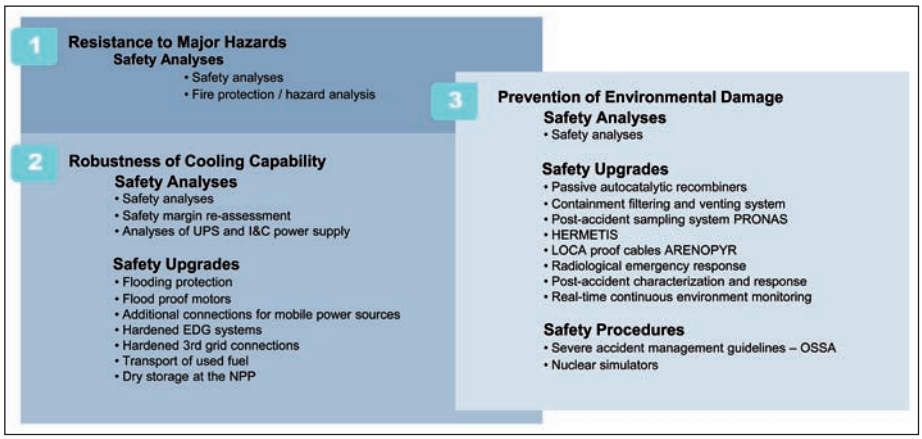

Fig. 4. Safety Alliance program for nuclear power plants in service.

commercial aircraft has been considered extensively in new constructions.

Areva has started the Safety Alliance program parallel to the *IAEA* requirements and the measures introduced by authorities. The nuclear company thus offers a comprehensive concept for safety inspections and for retrofitting measures, where necessary, with the aim to improve plant safety and meet stricter requirements imposed by authorities.

Safety Alliance program

The 3-part concept (*Figure 4*) consists of a safety analysis of the plant design in light of (natural) impacts from outside and inside. The main focus is to protect the safety features, for example through redundancy separation and "bunkering" so that external and internal impacts do not result in the simultaneous failing of multiple or all redundant sections of the safety systems.

In the event of a (natural) disaster, the functioning of the cooling chain and of the (emergency) power supply is crucial. *Areva* also offers the appropriate inspections and upgrade measures required for this purpose.

In a third stage, it is crucial to prevent radioactive material from escaping into the environment of the nuclear power plant in the event of a severe accident. For this task, *Areva* provides its competence in the form of analyses and retrofitting measures.

Goal: robustness of the safety concept

The term "robustness" as discussed by the reactor safety commission in its statement on the safety inspection of the German nuclear power plants in the aftermath of the *Fukushima* events is crucial in this context. Robustness in this sense encompasses especially the following aspects:

- The safety design of the plant should basically be "solid" enough to cope with events that have a potentially relevant impact on the environment (events with an occurrence probability of more than 10^{-4} to 10^{-5} per plant operating year).
- For even less probable ("beyond-design") events, so-called cliff edge effects should be avoided. This means that if the values on which the design is based (such as flood gauge or seismic intensity) are exceeded to a certain degree, the damages in the plant do in effect increase somewhat, but without abruptly increasing effects in the environments. An abrupt increase of the effects can usually be avoided by making use of design tolerances, or by applying anticipated emergency actions.

On the whole, a robust safety concept is achieved with an underlying solid design and measures to avoid cliff edge effects. Due to the consistently physical separation and "bunkering" of the individual redundant sections of the safety systems, a considerable robustness of the safety concept is ensured for the nuclear power plants in service in Germany. Against the background of the discussion following the statement of the reactor safety commission after *Fukushima* it is still being investigated whether and where the robustness can be further increased: for example, by preparing additional options that can be used to secure the power supply in the plants.

This consistent protection of the redundant sections of safety systems against external and internal impact (*Figure 5*) is only partially implemented in several older plants in the rest of the world. This is where *Areva* can offer a targeted development of plant-specific concepts to increase the robustness based on the available experience with the construction and the improvement of nuclear power plants. Examples include:

- installation of doors that withstand water pressure to separate redundant trains

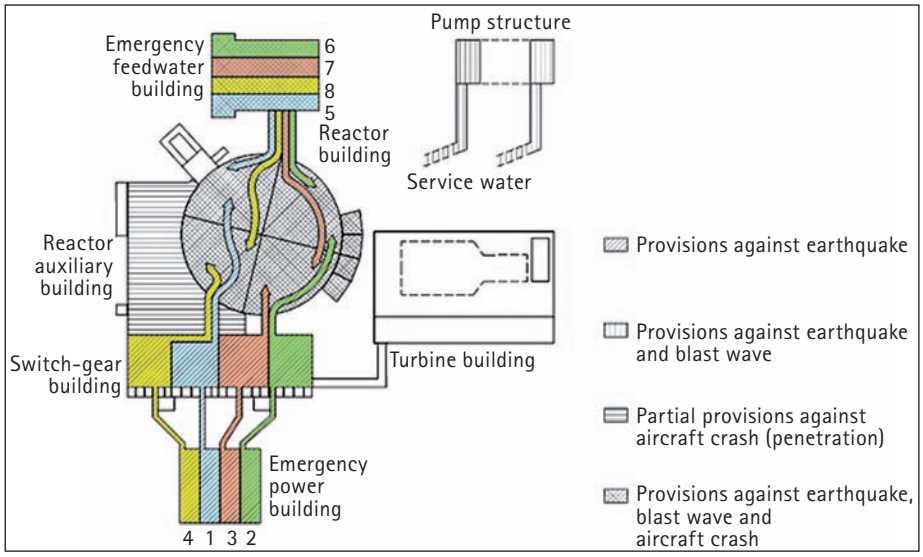

Fig. 5. Redundancy separation in German Konvoi plants.

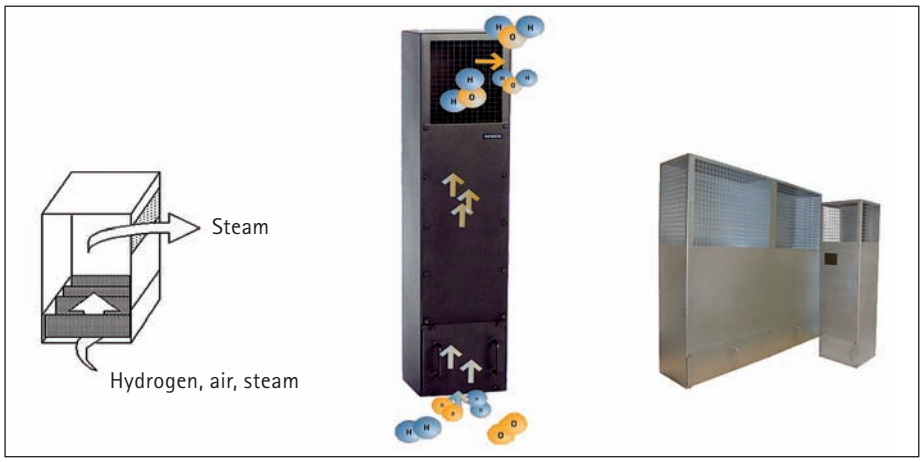

Fig. 6. Hydrogen recombiner.

- implementation of emergency power supply concepts with diverse features and special protection against external impact
- the installation of passive hydrogen recombiners that require no power supply (*Figure 6*) to prevent hydrogen explosions
- the installation of facilities that protect the containment against overpressure using a filtered pressure relief system (*Figure 7*).

New plants: accidents do not have an impact on the environment

Both the EPR™ units presently under construction in Finland, France and China and the *Kerena* and *Atmea1* reactor models developed or co-developed by *Areva* are of the latest generation III+. All models feature redundant, diverse and partially complementary (active and passive) systems to prevent and cope with accidents (*Figure 8*). Should severe accidents occur in spite of this, the plants' design ensures that the impact remains limited to the plant even in the event of a severe accident.

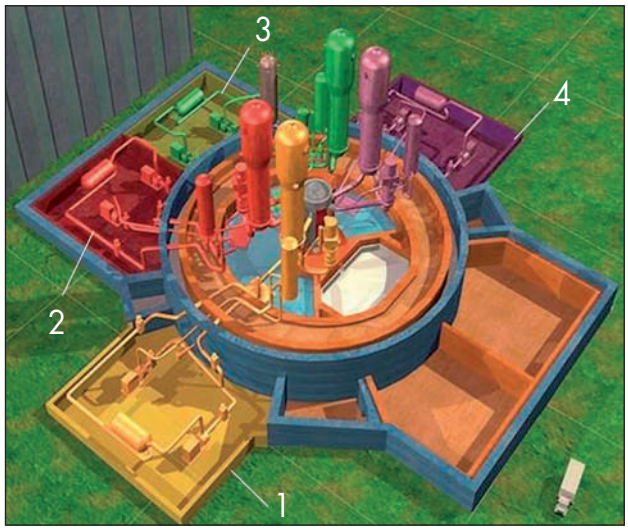

Fig. 8. EPR™ reactor: One section of the safety systems respectively is accommodated in each of the 4 safety buildings.

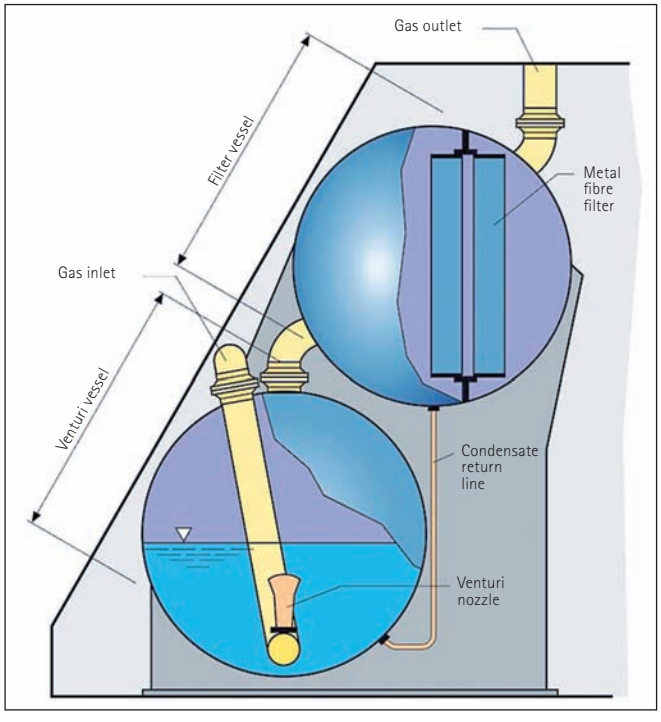

Fig. 7. Concept of the containment venting system.

Example: safety concept of the diesel generators of EPR™ plants

The diesel generators and the fuel tanks are accommodated in bunkered, explosion-proof, sealed and secured buildings. These are installed in separate locations and accommodate both the emergency power and the station blackout diesel.

Summary

The findings so far suggest that the insufficient design for tsunamis of the reactor units was responsible for the accident that occurred in the Japanese nuclear power plant *Fukushima Daiichi*. Thus the accident does not fall into the category of residual risk; rather it was due to the fact that the basic design for external impact was insufficient in this case. This is why the design and the safety concept of nuclear power plants must be reviewed with respect to possible improvement potential. This requires the corresponding expertise and the close cooperation of an experienced plant manufacturer, plant operators and authorities.

The reactor manufacturer *Areva* has undertaken to comply with the highest safety standards and to further develop these standards. Within the scope of the Safety Alliance program, the company offers operators of nuclear power plants a comprehensive range of engineering services and products to perform safety analyses and implement improvement measures. The increasing demand for concepts and products that enhance the robustness of safety concepts in plants worldwide, not only from Japan but from numerous other countries as well, can thus be served. The group's extensive experience in this domain is particularly advantageous in this context. New reactors are designed, licensed and constructed according to the highest safety requirements.

Compliance with the *IAEA* requirements is the basic prerequisite for the safe operation of nuclear power plants – and along with that for the acceptance of nuclear energy. *Areva* welcomes the international peer review envisaged within the scope of the stress tests carried out in many countries. This review is capable of harmonizing international requirements and will contribute to putting the concepts and the experience that are already available in some countries to the disposal of plants in other countries as well.

Despite the special situation in Germany, the use of nuclear energy on a global scale provides advantages in terms of energy and economic policy: because nuclear energy ensures reliable, economical and environmentally clean electric power. ■