EPR Accident Scenarios and Provisions

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ABSTRACT

For the EPR an improved defence-in-depth concept is applied. In an evolutionary way, accident control is developed from existing French and German PWR designs, thereby achieving a high safety level quantified by probabilistic safety assessment.

Independent of that, severe accidents are considered in the design. By a robust containment, and severe accident mitigation measures, the need for offsite emergency response actions (population evacuation or relocation) is restricted to the immediate plant vicinity.

1. Introduction

For existing light water reactors, in general a 3 level defence-in-depth approach is implemented consisting of

- first level: high quality in design, construction and operation for prevention of disturbances and accidents
- second level: Control and limitation of operational occurrences
- third level: Use of engineered safeguard systems for control of accident conditions

As the EPR relies on the proven designs and technologies implemented in French N4 and German Konvoi PWR plants, it also relies on the defence-in-depth approaches realized in those designs. The objective for the EPR was to introduce improvements on all of the levels of defence in an evolutionary way and thereby to decrease the probability of occurrence of a severe accident with partial or even full melting of the core.

Beyond that, the Safety Authorities in France and Germany have required that measures should be taken at the design stage to limit the consequences of severe accidents involving complete core meltdown. These requirements, formulated by the French Groupe Permanent Réacteur and the German Reaktor-Sicherheitskommission, and issued by the DSIN and BMU, stipulate that there must not be a need for evacuation of surrounding populations ex-

cept in the immediate vicinity of the NPP site, and for long term restrictions with regard to the consumption of locally grown food.

For this purpose, the EPR design realizes beyond the evolutionary approach an additional level of defence

fourth level: Mitigation of severe core damage consequences

by introducing measures and layout features for severe accident mitigation and by strengthening the confinement function.

2. Consideration of accidents for EPR design (severe accident prevention)

For severe accident prevention, 2 groups of accidents are considered for EPR design: accidents within the deterministic design basis, and accidents considered for further risk reduction:

2.1 Deterministic design basis

Within the deterministic design basis initiating events from any initial conditions (power states, shutdown states) are selected according to their potential risk with regard to the main safety functions:

- reactivity and core power control
- heat removal from the fuel elements
- confinement of activity

and classified according to their frequency into anticipated operational occurrences (PCC 2), as well as infrequent (PCC 3) and limiting (PCC 4) accidents.

The rules for the analysis of these design basis accidents have been harmonized between France and Germany in the following way: It is shown, that a short-term controlled state, and a long-term safe shutdown state are reached relying only on especially classified systems (F1 systems). These F1 systems are designed according to strong deterministic rules (e.g. redundancy, train separation in order to protect against internal hazards like fire or flooding, protection against external hazards as earthquake and aircraft crash). Design basis accident analysis is done assuming unavailability of trains due to single failure and preventive maintenance within these systems and implementing conservatism where appropriate. Non-F1-classified systems are only considered where their operation is penalizing.

2.2 Risk reduction

In order to achieve an acceptable core melt frequency level, for EPR design, the following targets have been defined:

- The overall core melt frequency objective (all events) is 10^{-5} per reactor and year
- The integral core melt frequency for internal events from power operation shall be less than 10^{-6} per reactor and year (design target)

- Shutdown states shall contribute to the overall core melt frequency less than power states
- Core melt with large and early containment releases shall be practically eliminated.

In order to meet these targets, in addition to the deterministic design basis event sequences are selected on a probabilistic basis as far as they provide a design basis for additional diverse systems. These diversified systems are classified at least F2. The main requirement for F2-systems is operability under the conditions of the relevant event sequences.

Fig. 1 gives the RRC-A event sequences considered so far for the design of F2-classified features, diverse to F1-classified safety functions. These RRC-A sequences are analyzed according to best-estimate assumptions e.g. with regard to the availability of systems, and to proven modeling.

3. Preliminary probabilistic assessment of the EPR

In order to demonstrate compliance with the probabilistic targets and to achieve a well balanced design, during the Basic Design Phase a probabilistic safety assessment (level 1) was performed.

This safety assessment has to be considered as preliminary because beside others

- the spectrum of sequences analyzed so far is not fully complete
- generic equipment failure data have been used
- generic conservative common-cause failures on the basis of β -factors have been assumed
- simplified human failure assumptions have been taken because of lack of detailed accident procedures
- I&C has not systematically been modeled
- preventive maintenance is not considered.

Nevertheless, from the results (Fig. 2) the following preliminary conclusions can be drawn:

- The design targets for the overall core melt frequency will be met. The contribution of shutdown states is only about one third of the one of power states.
- The contributions from the various sequences are well balanced; there is no sequence which dominates the core melt risk.
- Sequences with large and early releases (high pressure core melt sequences, bypass sequences) are about 1 order of magnitude less likely compared to the already very unlikely low pressure sequences. Compared to the overall core melt frequency objective for a complete PSA, their contribution is negligible, and therefore, they can be considered practically eliminated.

4. Mitigation of Severe Accidents

Despite their extremely low expected overall frequency, severe accidents and their consequences are taken into account in the design of the EPR. In order to avoid severe consequences for the environment and for the population, containment integrity and leaktightness shall be maintained during the entire course of potential severe accidents.

Processes which could occur during severe accidents and which could jeopardize containment integrity and lead to enhanced fission product release were identified in various risk studies. They include

- risk of failure of the reactor pressure vessel (RPV) at high pressure due to an attack of the molten core with risk of corium dispersal and direct containment heating (DCH)
- energetic interaction of molten fuel and coolant in-vessel and ex-vessel (MFCI)
- interaction of molten corium with the basemat with the possibility of basemat melt-through
- risk of fast hydrogen deflagration or detonation
- long-term pressure and temperature increase in the containment.

The general approach for the EPR is

- to prevent or eliminate by dedicated design measures those scenarios which are connected with high loads, such as high pressure failure of the RPV or global or local hydrogen detonation
- to mitigate the consequences of low pressure severe accident scenarios by specific design measures in such a manner that the containment retention function is maintained.

The chosen technological solutions should be uncomplicated, transparent and robust to avoid any technological or constructional problems. Further, they should be compatible with the overall design features of the plant and with operational needs to avoid any new kind of accident initiator and to guarantee an economic plant operation.

The resulting containment design of the EPR is shown in Fig. 3.

High pressure failure of the RPV is eliminated by deliberate depressurization of the primary system to a pressure below 20 bar using a highly reliable dedicated valve. In addition, the load-bearing capability of supporting structures in the reactor cavity are increased. The depressurization also prevents the risk of direct containment heating, and of creep failure of the steam generator tubes which could induce a radiological containment bypass.

The design of reactor pressure internals including the heavy reflector should limit the amount of molten fuel interacting with coolant and hence limit local dynamic pressures. Extensive R&D has been performed which tends to prove that an energetic interaction is self-limiting, and that the resultant loads would not lead to the creation of large missiles which could endanger containment integrity.

Ex-vessel steam explosion loads are prevented by constructional means in the reactor pit suited to minimize water accumulations in a loss of coolant accident (LOCA). The compartment dedicated to melt spreading is initially dry and only thin water films may develop because of steam condensation. Intentional flooding of the melt for cooling and stabilization will be performed at a low rate.

Against basemat penetration, a corium retention device is included in the EPR safety design. The basic concept is spreading of the melt on a large surface outside of the reactor cavity, thus separating the short term mechanical and thermal loads from the region of final stabili-

zation. After RPV melt through, the melt will first be retained in the cavity for about 1 h to achieve quantitative collection and to condition the melt by reaction with sacrificial material. After opening of a melt gate, the melt is directed to the spreading compartment having a surface area of about 170 m². Refractory material in the spreading compartment ensures long-term thermo-chemical stability. Melt spreading and the choice of sacrificial and protective material are supported by extensive R&D. A cooling loop which is part of the long term containment heat removal system is installed below the floor of the spreading compartment and protects the structural concrete from thermal loads. Connections to the internal refueling water storage tank (IRWST) are passively opened and water enters the spreading area to flood the melt from above. The steam generated during the cooling process escapes to the containment.

Hydrogen is controlled and mitigated by a system of around 40 recombiners within the equipment compartments and, in addition, of some igniters at the IRWST openings which remove the hydrogen released in non-LOCA scenarios through the IRWST at an early stage. The system is designed to prevent global detonation and deflagration to detonation transition (DDT). The containment has a free volume of 80000 m³, and a design pressure of 6.5 bar, in order to be able to cope with a global hydrogen deflagration.

Long term pressurization of the containment is avoided by a dedicated active containment heat removal system which needs to operate not earlier than 12 h into the accident. The building structures provide sufficient heat capacity so that the design pressure is not exceeded within the uncooled period. The external recirculation cooling loop is located in a special ventilated and shielded compartment with provisions for decontamination and repair.

The confinement system practically eliminates direct containment releases, collects containment leakages in the annulus for a filtered release via the stack, and contributes to avoid stringent countermeasures outside the immediate plant vicinity like evacuation, relocation or food control.

5. Conclusion

For the EPR, improvements in core melt prevention compared to existing German Konvoi and French N4 plant result in extremely low core melt frequency figure. Nevertheless, core melt is postulated deterministically in order to prevent the need for stringent offsite emergency response actions. Thereby, an overall safety level is achieved which is unique for large evolutionary PWRs.

Initial state	RRC-A event combinations considered	Diversified back-up features
Any stationary plant state	Loss of offsite power and of large diesels	Small diesels power supply, primary pump standstill seals, EFWS
Secondary side heat removal	Loss of ultimate heat sink	Water supplies on secondary side, independent cooling of various components
	ATWS	Pressurizer valves, secondary side cooling and extra boration system
	Total loss of feedwater (MFWS SSS, EFWS)	Primary bleed and feed
	Small LOCA and loss of MHSI	Fast secondary side depressurization, accumulators and LHSI
	Small LOCA and loss of LHSI/CCS/SWS	CHRS and MHSI

RRC-A Risk reduction category A (core melt prevention)

MFWS Main feedwater system
 EFWS Emergency feedwater system
 SSS Startup-shutdown feedwater system
 RCS Reactor coolant system
 CHRS Containment heat removal system
 LHSI Low head safety injection
 MHSI Medium head safety injection
 CCS Component cooling system
 SWS Service water system

EPR, RRC-A event combinations and associated diversified back-up features

Fig. 1

EPR, Preliminary results of level 1 PSA

Fig. 2

EPR, Containment design for
severe accident mitigation

Fig. 3