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Evaluation of a preliminary safety concept for the HPLWR

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ABSTRACT

The main safety functions considered in the preliminary concept for the High Performance Light Water Reactor (HPLWR) have been evaluated by means of a comprehensive set of analyses, which have been performed using system and coupled codes. The investigated scenarios addressed a variety of initiating events, including anticipated transients as well as accidents. The simulations performed show that for each class of transients at least one of the computational tools used in this project is adequate for preliminary assessment of the safety concept of the HPLWR. The analyses have shown that the proposed systems can be expected to be capable to provide all the safety functions. The open issues that remain to be addressed in future projects are also discussed.

1. Introduction

The High Performance Light Water Reactor (HPLWR) is the European contribution to the supercritical water-cooled reactor concept. The results presented here summarize the main findings of the safety analyses performed within the project HPLWR 2 of the Sixth European Research Framework Programme (Schulenberg et al., 2009). The main characteristics of the current design have been presented in various publications (e.g. Schulenberg at al., 2008; Schulenberg et al., 2009; Starflinger et al., 2011), and will not be reported here. The specific three-pass core concept, however, is illustrated in Fig. 1, as this is a design feature that has a major effect on the system response and therefore on the safety analysis. The concept includes a thermal core in which supercritical water is heated up in three steps (evaporator, superheater 1 and superheater 2) with intermediate coolant mixing to minimize peak cladding temperatures of the fuel rods. The general safety concept, basic requirements and safety goals have been established, and a preliminary design for the safety systems has been proposed (Bittermann et al., 2009). In this paper, the current configuration and the main safety functions will be briefly discussed. The main focus of the work is on the results of the safety analyses, which provide a first evaluation of the capability of the systems to provide the required safety functions.

2. General safety systems configuration

In case of most of the transients as well as in the event of accidents, the following safety functions must be assured:

- Reactor scram
- Containment isolation
- Reactor Pressure Vessel (RPV) pressure relief and depressurization
- Heat removal from the RPV
- Reactor water makeup and control of core coolant inventory
- Heat removal from the containment

The general HPLWR safety systems configuration schematic is shown in Fig. 2. It includes:

- Safety Relief valves (SRV), which can be actuated to provide an Automatic Depressurization System (ADS)

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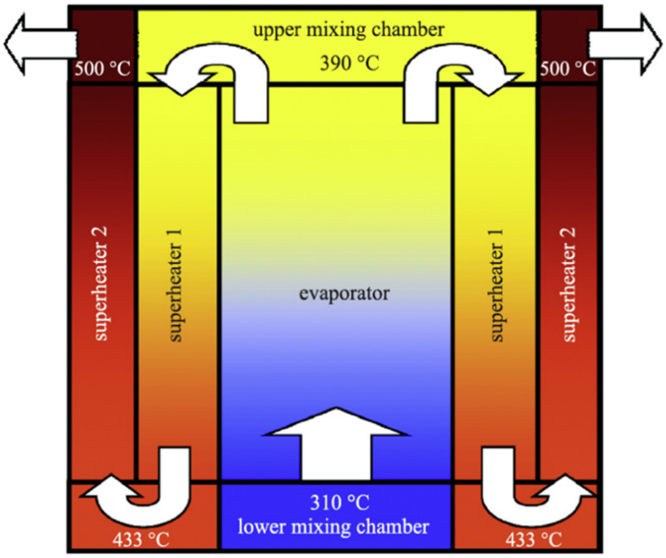

Fig. 1. Three pass design concept of HPLWR core (Schulenberg et al., 2008).

- Residual Heat Removal (RHR) and Low Pressure Coolant Injection (LPCI)
- Containment condensers

The specific characteristics of the current HPLWR design which influence the safety of the reactor with respect to core cooling have been compared with those of typical PWR and BWR designs, and the issues related to the differences that have been identified gave important hints for design measures (Bittermann et al., 2009). The specific characteristics to be considered for safety concept development are as follows:

- Water mass in the primary circuit and associated heat storage capacity
- Cooling of the core in the case of loss-of-flow conditions
- Heat capacity of the core
- Heat transfer mechanisms within the core after shutdown under specific conditions
- Challenges stemming from the transition from supercritical single flow regime to subcritical two-phase flow conditions in case of Loss-of-Coolant Accident (LOCA)

The safety analyses presented here will especially address the issues above.

2.1. Analyses performed to dimension the safety systems

A preliminary dimensioning of the safety systems was performed using the code APROS developed by VTT Technical Research Centre of Finland and Fortum. The HPLWR whole steam cycle was modeled and analyzed for part load, shutdown and start-up conditions (Schalegenhaufer et al., 2010). The simulation of complete containment isolation with following depressurization through the ADS showed that the reactor can be cooled efficiently. The ADS actuation pressure, the ADS valves flow area, the ADS valves driving time and the Main Feedwater Isolation Valves (MFIV) and Main Steam Isolation Valves (MSIV) driving time were varied. These studies indicated that an ADS actuation pressure of 26 MPa, a flow area of 0.09 m^2 and a driving time of 0.2 s are an optimal set of parameters. The simulation of the LPCI system showed no principle drawbacks. The reactor can be cooled efficiently after the system is depressurized through the spargers. After the LPCI system injects water at 6 MPa in order to fill the reactor with water, the cladding temperature starts to rise again. The simulation shows that nominal mass flow rate 400 kg/s for the pump almost prevented the rising of the cladding temperature, since the core was flooded. With this initial choice of systems and parameters, a preliminary safety assessment was conducted, which is presented in Section 3.

3. Safety analyses

At the beginning of the project, the events to be analyzed have been classified according to the current practice into different categories and to these categories different acceptance criteria are applied (Bittermann et al., 2009). The full list of events (104 events) to be considered for the HPLWR safety analyses has been provided at the beginning of the project by AREVA. The first analyses were intended to cover some events which would enable an assessment

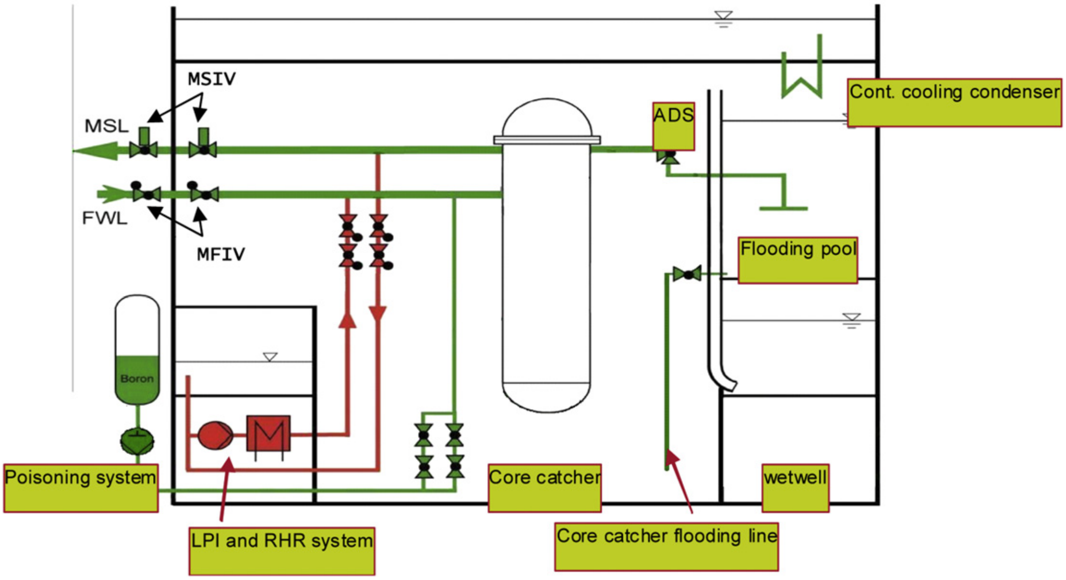

Fig. 2. General configuration of the safety systems.