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Forced Core Flow Mixing Tests

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1. Introduction

The flow mixing behaviors between the main coolant and injected emergency coolant at the cold leg of a Cold Leg Injection (CLI) system or at the downcomer of a DVI system, as well as at the core inlet are very important during a transient operation such as rapid boron dilution or unborated pure water injection events, including overcooling transients during a Loss of Condenser Vacuum (LOCV) event. For such system flow mixing behaviors, well defined and multi-dimensional mixing tests are required with a system-integrated-and-scaled test facility. Here a benchmarking experiment is conducted for the assumption of the perfect mixing volume representing prototype plant behavior during an unborated pure water injection event. The borated water distributions at the cold leg and core inlet were identified by measuring the conductance distribution using a wire mesh sensor [1]. The split factor or mixing factor, defined using the unbalancing flow ratio between the hot legs, is identified by measuring the impedance transport [2].

2. Test Facility

2.1 Scaling

The reactor vessel, internal structures and loops of the test facility are reduced to a 1/5 linear scaling ratio to design scaled copies of the PWR prototype. Table 1 summarizes the scaling parameters for the 1/5-scale model.

The aspect ratio (L/D) and shapes of the major flow paths, channels and body geometries are preserved. The flow Euler number of the prototype reactor has been preserved in the test facility. The Reynolds (Re) and Euler (Eu) numbers are usually considered important non-dimensional parameters to ensure flow mixing similarity for the single phase flow mixing. However the turbulence effects on flow mixing at the high Reynolds number of a fully turbulent flow do not differ between the proto type and the model if the Reynolds number is high [3,4].

To preserve the flow rate distribution in a scaled reactor model, the L/D aspect ratio of should be held to 1.

2.2 Test Facility

The test facility includes several subsystems, in this case a Shutdown Cooling System (SCS) and a Chemical and Volume Control System (CVCS). The SCS and CVCS are used in boron dilution tests. The CVCS simulates the flow mixing behaviors of a pure water slug due to inadvertent operation of the CVCS during the shutdown cooling mode. For the pure water mixing test under isolated loop flow conditions, the four Reactor Coolant Pumps (RCP) are stopped and the loop is isolated by valves. The CVCS is then injected with a tracer at a high concentration in a comparison with RCS water.

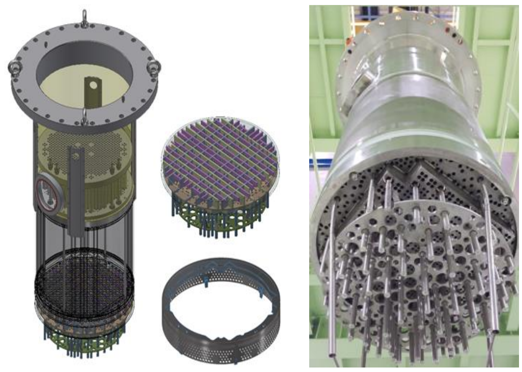

Fig. 1 Core barrel and internals and photo

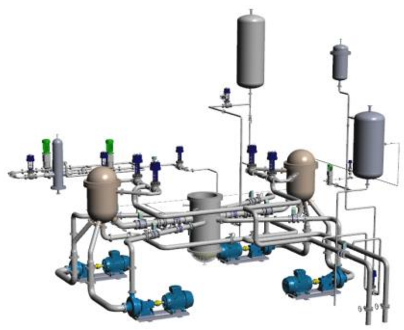

Fig. 2 Test facility

Figure 1 shows the core barrel, lower support plate and flow skirt. Three different core models were developed, in this case cavity, pipe, and mixing vane types, to represent realistic models. The cavity model simulates the core as a blank region. The pipe model simplifies the core as pipes having a similar flow area. This model does not allow a cross flow. The mixing vane model, with a spacer grid, has holes with a pressure drop similar to that of the prototype. Figure 2 shows the bird's eye view of the overall loop configuration of the REMIX test facility.

3. Results

Fig. 3 shows a nondimensional pure water concentration transient representing boron mixing at the downcomer. The upper curves represent the minimum while the lower curves represents the averaged value of the boron concentration. The conductance of the RCS coolant decreases linearly due to the injected pure water and the letdown flow. The reactor flow is driven by the SCS pump and by the CVCS injection, but the SCS pump flowrate is much higher the rate of the CVCS injection. The boron dilution time constant of the evaluation model for perfect boron mixing could be quantified using these data.

Fig. 4 shows a typical conductance transient representing a core mixing factor transient at two hot legs for the forced convection flow driven by RCPs. The plateau period of conductance represents the tracer injection period. The injected tracer into the CL-1A flows into the two hot legs after passing through the reactor vessel and core for injection phase-1. The time lag between the CL-1A injection and the hot leg detection time is approximately 1.7 sec for the high convection mode driven by the four RCPs. Subsequently, the conductance values of the hot legs are increased again by the loop recirculation of the injected tracer of CL-1A for injection phase-2.

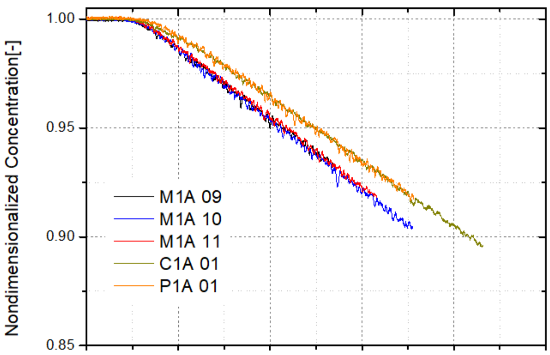

Fig. 3 Mixing concentration at the downcomer

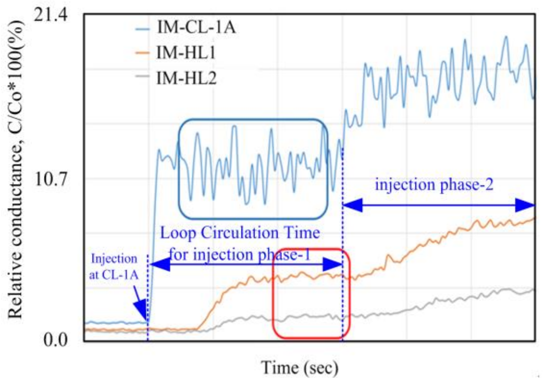

Fig. 4 Conductance transient at CL-1A and HL-1/2

4. Conclusions

The reactor mixing factors were identified using flow-averaged impedance sensors while the local distribution of the boron or mixing scalar was measured by wire mesh sensors. These validation tests will strongly contribute to the approval of the standard design of the power reactor. At the same time, these test data will contribute to the code validation processes both the CFD and the nuclear reactor safety analysis codes. The database can also be used to quantify of the performance capabilities of various multi-dimensional flow behavior predictions of reactors.

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