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PHEBUS FPT-1 simulation by using MELCOR and primary blockage model exploration

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HIGHLIGHTS

- Flow channel blockage model is expected to be the key parameter for hydrogen generation calculation.
- Flow channel blockage situation is studied in this work.
- MELCOR is used as the tool, and PHEBUS FPT1 is used as benchmark.
- Model sensitivity analysis on hydrogen generation will be done in next step.

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ABSTRACT

Recently, MAAP and MELCOR research teams completed a set of accident simulations to reconstruct the Fukushima-Daiichi accident in order to better understand severe accident progression. One result from this work is that the predicted hydrogen generation in MELCOR is notably more than that in MAAP. The fuel rod degradation process (i.e., debris formation and blockage models) may be responsible for this difference and opportunity exists to understand the key reasons for the difference. To examine this hypothesis, in this paper, the PHEBUS FPT1 experiment is selected as a benchmark test and MELCOR is used as the analysis tool. MELCOR calculation results are compared with PHEBUS FPT1 data to verify our model. Based on the validation of a nominal MELCOR simulation of the FPT1 test, we use the volume fractions of each component to visualize the debris-blockage geometric arrangement for PHEBUS FPT1 as the fuel degradation event proceeds. Cloud figures for the volume fractions of each component such as flow volume fraction, cladding volume fraction, fuel rod volume fraction, supporting material volume fraction, non-supporting material volume fraction and debris bed porosity fraction are shown in this paper. The results provide us with a visualized approach for improving our understanding of core degradation.

1. Introduction

The core degradation process is critical in the progression of a severe accident because it provides the initial conditions for subsequent phenomena in and out of the containment vessel, which often lead to events that may damage the containment and provide hydrogen source terms (Hofmann, 1999). Core degradation will inevitably constitute a grave threat to the safety of a nuclear power plant and the public nearby (Gaunt et al., 2012), so it is important for us to accurately simulate and predict the progression of core degradation. However, current studies on severe accidents have been insufficient to accurately predict their consequences (Sehgal, 2012). A recent research by Wachowiak et al. compares the simulations result of Fukushima core degradation made by MELCOR and MAAP (Wachowiak, 2014). MELCOR's blockage model is different with MAAP's blockage model, as shown in Fig. 1 (MAAP left). After blocking, MELCOR is allowed to have 5% steam flowing through the blocked molten pool, which produces lots of hydrogen. However, the MAAP doesn't allow the steam to pass, which makes the hydrogen production of MAAP is quite smaller than MELCOR.

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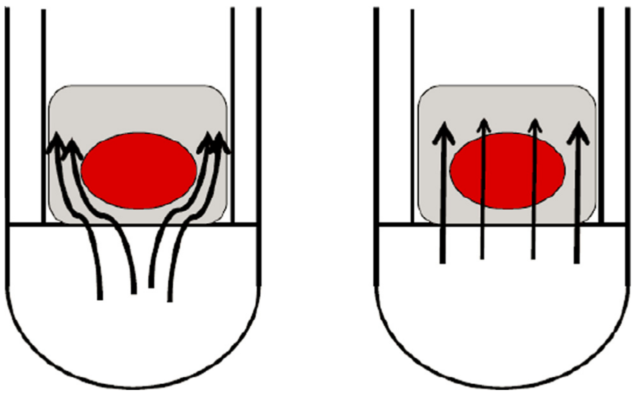

Fig. 1. Flow blockage model of MAAP and MELCOR (Wachowiak, 2014).

The comparison result shows that both codes can model the Fukushima accident with consistent initial and boundary conditions and with appropriate modeling and parameter assumptions. The calculation results such as pressure and temperature history and certain early event timing match the observations. However, certain key physical processes differ, e.g., prediction of the hydrogen generation in MELCOR is notably more than that in MAAP. As a consequence, opportunity exists to understand the key reasons for this difference. The fuel rod degradation and flow blockage processes, which involve clad oxidation, fuel-clad melting, candling and freezing, debris formation, flow blockage model and heat transfer, may be responsible for the hydrogen generation difference.

In order to gain a better understanding of core degradation progression, the mechanism of core blockage in severe accident conditions has been extensively studied in the past, especially since the TMI-2 accident and the latest Fukushima accident. In 1978, the mechanism of partial flow blockage in turbulent flow in a nuclear fuel rod bundle model was studied by Creer et al. (19790. Then Ang et al. analyzed the flow distribution in a PWR fuel rod bundle model containing a blockage (Ang et al., 1987, 1988). Two years later, the cross-flow between identical sub-channels caused by a

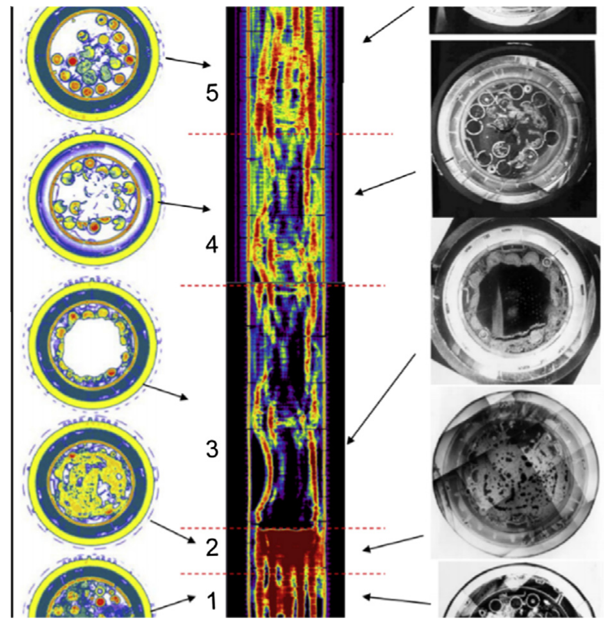

Fig. 3. Radiography and tomography of test bundles (Barrachin et al., 2013).

severe blockage was studied by Gencay and Tapucu (1991). During this period, several notable experiments about core degradation, including blockage mechanism research, were conducted, such as CORA (Firnhaber et al., 1993), QUENCH (Hofmann and Noack, 1992), and PHEBUS (Connier et al., 1992). A model for melt blockage (slug) relocation under severe accident conditions was developed by Veshchunov and Shestak (2008). This new model demonstrates a reasonable capability to simulate the main features of the massive slug behavior observed in the CORA test. In the same year, Drai et al. improved the core modeling in ICARE/CATHARE by taking multidimensional flows and heat transfers into consideration (Drai et al., 2008). Later, a flow blockage analysis was done by Lu et al. (2009). This topic was also studied in severe accident research in the core degradation area by Bottomley et al.

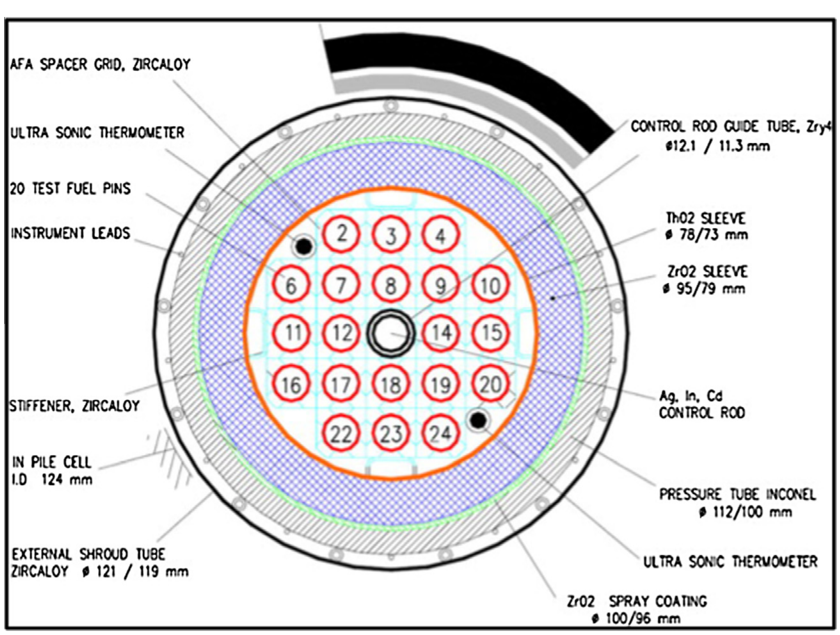

Fig. 2. Fuel assembly scheme (March and Teisseire, 2013).