Simulation of Ignition Phenomena in Spent Fuel Assemblies in a Complete Loss-of-Coolant Accident

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1. Introduction

OECD/NEA has conducted an international research program, SFP (Sandia Fuel Project), on the ignition phenomena at spent fuel assemblies after a postulated complete loss-of-coolant accident in spent fuel pool [1]. The project aimed to perform a highly detailed thermal-hydraulic characterization of full length, commercial fuel assembly mock-ups to generate data for the validation of severe accident codes such as MELCOR. SNL (Sandia National Laboratories) successfully completed all the experiments through Phase I tests for a single assembly and Phase II tests for five assemblies of the 1x4 arrangement as shown in Fig. 1.

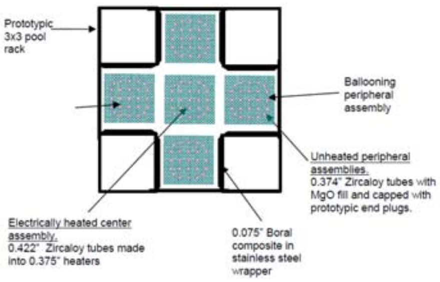

Fig. 1 1x4 arrangement for SFP Phase II

KINS has participated in the program and contributed with benchmark calculations using MELCOR code for both the SFP ignition tests. This paper summarizes the calculation results as well as the modeling assumptions considered in the benchmark calculation for the Phase II ignition test [2].

2. Methods and Modeling

2.1 MELCOR Code

In this study, MELCOR 1.8.6.yv.3084.SFP which had been provided by SNL was used in a 32-bit environment with Windows-7 OS.

2.2 Nodalization and Modeling Options

The nodalization used in the calculation is shown in Fig. 2. The model consists of 17 axial levels and 3 radial rings. The axial levels include the base plate and pipes in the lower plenum, bottom nozzle, active core region, the plenum region and the top nozzle. For radial

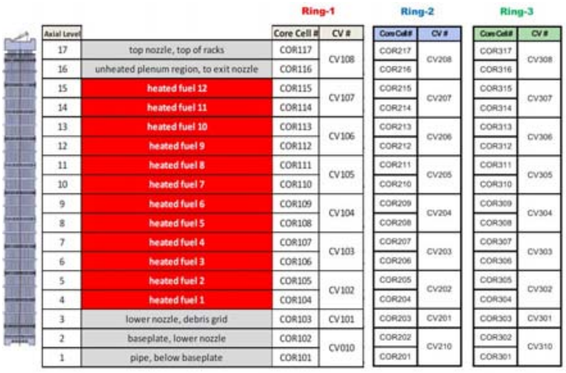

Fig. 2 MELCOR Nodalization for SFP Phase-II

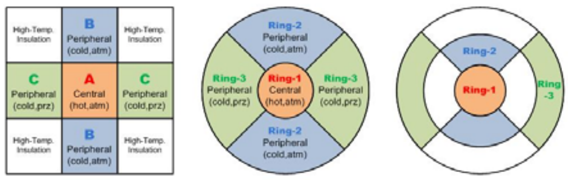

Fig. 3 Application of 3-ring model

rings, the unheated peripheral assemblies were modeled with Ring-2 (unpressurized rods) and Ring-3 (pressurized rods). For the core rings, conceptual diagrams are shown in Fig. 3. A 3-ring model has been considered to simulate the ballooning effects in pressurized assembly, if necessary.

Using the 3-ring model, the core boundary heat structure is applied only in Ring-3 as its definition in COR Package of MELCOR. This type of model might not simulate the direct heat transfer from the central assembly to the peripheral ones modeled as Ring-3. To overcome this limitation, the arbitrary heat transfer path using CORHTRxx input was introduced and finally applied as heat transfer path between Ring-2 and -3. With this modeling option, the heat transferred to Ring-2 can be shared with Ring-3 and the heat from the central assembly to Ring-3 is effectively simulated. In the Ring-3, the flow area was controlled using a valve option to simulate the effect of ballooning at the level where the phenomenon is expected to occur.

2.3 Initial and Boundary Conditions

All the control volumes have the initial pressures of 83.8 kPa and temperature of 300 K. They contain 80%

of nitrogen and 20% of oxygen, without any H_2O contents in the air. The initial decay heat of 11.6 kW which corresponds to 77.3% of the experimental input was modeled in the central assembly, Ring-1 in COR package.

3. Results

The best estimate analysis results have been produced mainly concentrated on the identifying the time of ignition onset. As shown in Fig. 4, the temperature profiles for central and peripheral assemblies are reasonably in good agreements between experiment and analysis. After ignition, however, the analysis overestimated the cladding temperatures in all assemblies, while there was slight overestimation before the time of ignition. This is shown again in Fig. 5 in which the average cladding temperatures at the time just before ignition are compared between experiment and analysis, as the function of elevation.

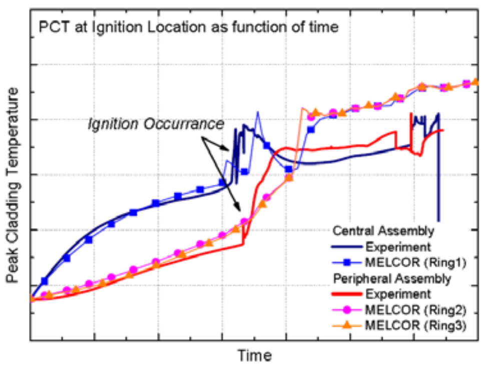

Fig. 4 Comparison of Peak Cladding Temperatures

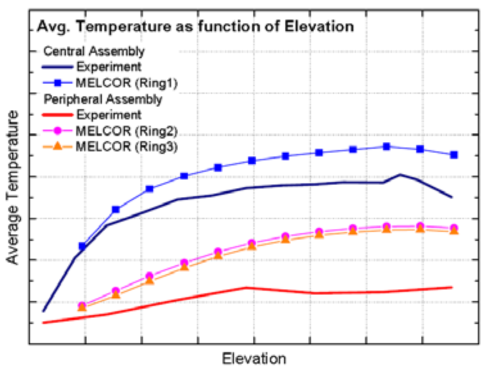

Fig. 5 Comparison of Average Cladding Temperatures as Function of Elevation

In mass flow rate at the assembly inlet, a significant discrepancy was found. From Fig. 6, the initial maximum flow rate in central assembly was well predicted thereafter, however, the flow rate in central assembly was underestimated. The opposite results were found in the flow rates in peripheral assemblies comparing the analysis results (Ring-2 and -3) with the experimental results.

Though the 3-ring model was introduced to simulate the effect of ballooning of the rods which was

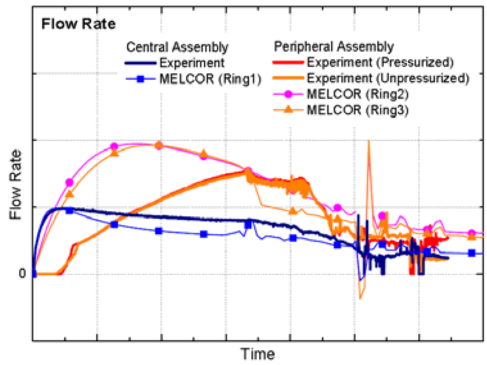

Fig. 6 Comparison of Flow Rates

simulated in the experiment with pressurized rods, no significant effects were found in the analysis. This is identical to the corresponding finding in experiment. With this 3-ring model, the running of MELCOR code was successful. However, there is a limitation with this modeling concept that should distort the real assembly arrangement as well as the heat transfer. The application of this modeling to the analysis for the real spent fuel pool may need an improvement in the treatment of the geometrical array of assemblies and its related heat transfer.

4. Conclusions

The experimental results obtained in Phase II ignition test of the OECD-SFP project obviously showed that the ignition could occur after a complete loss-of-coolant accident in spent fuel pool. The ignition phenomenon was well predicted with the MELCOR code using 3-ring model in COR package, while there are some limitations in the prediction for overall temperature and flow rates, etc. The experiences and results obtained from this study may contribute to the later studies on the spent fuel pool under an extreme condition that can be generated by a seismic event like Fukushima accident.

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REFERENCES

[1] USNRC, Agreement on the OECD/NEA SFP Project: An Experimental Programme and Related Analyses for the Characterization of Hydraulic and Ignition Phenomena of Prototypic Water Reactor Fuel Assemblies, Dec. 2010.

[2] T. Hollands et al., Specification Report on Benchmark Sandia Fuel Project Phase II: Ignition Testing (Draft), Aug. 2012.