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MELCOR 1.8.5 Assessment of Molten Core Concrete Interaction Experiment SWICCS-4

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I. Introduction

In a postulated core melt accident, if the molten core is not retained in-vessel despite taking severe accident mitigation actions, the core debris will relocate in the reactor cavity region. There, it will interact with structural concrete and could potentially result in basemat failure (through erosion or overpressurization) and consequent fission product release to the environment. Although a methodology of cooling the molten core by adding water on its top is selected as a severe accident management strategy in case molten core is released outside a reactor vessel, the possibility of a long-term cooling is still unresolved. In the OECD/MCCI project scheduled for 4 years from 2002. 1 to 2005. 12, a series of tests are being performed to secure the data for cooling the molten core spread out at the reactor cavity and for the long-term CCI (Core Concrete Interaction). The tests include not only separate effect tests such as a melt eruption, water ingression, and crust failure tests with prototypic material but also 2-D CCI tests with a prototypic material under dry and flooded cavity conditions.

In this study, SWICCS-4, one of the SWICCS tests of OECD/MCCI project, was assessed using MELCOR1.8.5 and the computer code deficiencies were investigated including several sensitivity studies.

II. Experimental Background

The SSWICS series of tests is considered complete. Parametric variations of the completed tests are summarized in table 1. The SSWICS reaction vessel (RV) has been designed to hold up to 100 kg of melt at an initial temperature of 2500°C. The RV lower plenum consists of a 67.3 cm long, 45.7 cm (18”) outer diameter carbon steel pipe (figure 1). The pipe is insulated from the melt by a 6.4 cm thick layer of cast MgO, which is called the “liner”. The selected pipe and insulation dimensions result in a melt diameter of about 30 cm and a surface area of 707 cm^2. The melt depth at the maximum charge of 100 kg is about 20 cm. Figure 1 is a schematic that provides an overview of the entire SSWICS melt-quench facility.

Water injection was initiated at 108 s at a flow rate of about 13 l/min, lasting for 3 minutes (ending at 303 s) and resulting in an integrated flow of approximately 40 liters. Once all the water had been injected, the control valve VC-CT was switched to automatic mode so that it could begin regulating system pressure. The valve immediately began to close, which caused the pressure to rise towards the set point of 4 bar. The set point pressure was surpassed at 1023 s and soon after the system stabilized with slow oscillations between about 4.02 and 4.05 bar. The pressure oscillations had a period ranging from roughly three to five minutes.

The quench rate of the melt was significantly lower than that observed in previous tests, as shown by the reduced temperature differential across the heat exchanger and the longer test duration. After about 2.4 hours, the thermocouples within the thermowell reached the saturation temperature and the test was terminated.

III. Modeling

For the MELCOR simulation, it is necessary to set up an appropriate scaling methodology, since geometrical differences exist between the CCI tests and the MELCOR simulations. In the CCI tests, the concrete ablations could proceed to one ablative bottom wall and two ablative side walls in the rectangular geometry. Whereas, in the MELCOR simulations they could proceed to the bottom wall and side wall in the cylindrical geometry. The melt of 100 kg was contained in a test section. The solidus and liquidus temperatures are excerpted from CORCON concrete in MELCOR manual whose compositions are very similar to LCS concrete used in this test. The initial temperature of melt was obtained from the OECD/MCCI test results.

There are total seven control volumes in the simulation. Water is injected at 13 liter/min from 108s to 303s and total injected water is 40 liters.

IV. Results and Discussion

The MELCOR base calculation was performed using defaults input options. In Figure 3, the all calculation results were shown without mixing option. Initially, Corium ignition started and temperature of corium increased rapidly in experiment. In calculation, initial corium temperature set to the experiment and heat transfer to the surround structure/air made corium temperature decrease slowly. As the temperature decrease, crust is formed at corium outside surfaces and temperature decreasing rate reduce. At 108 seconds, water injection start and corium temperature rapidly decreased due to the quench process. After crust formed, the heat transfer rate decreased and boiling heat transfer in surfaces and conduction/convection heat transfer was occurred in test section. From the crust formation time to end of experiment, the boiling heat transfer was the only way of heat removal process. The water cooling makes corium temperature decrease gradually.

In MELCOR base calculation (use default values in CAV package), the initial rapid temperature decrease was predicted well, but after the end of rapid temperature behavior, temperature decreasing rate is higher than that of experiment. In order to identify the reason, sensitivity study was performed. The corium conductivity multipliers, corium emissivities and oxidic/metallic mixing option were selected. In these cases, the temperature decreasing slopes were slightly changed but the rates were still quite different from experiment. As a next, the mixing option was selected as 1 which means "calculate mixing and separation rates from correlation". In Figure 4, this case result was shown. Due to mixing, HMX, HOX and MET layer were shown and temperature of corium predicted well. Because CAV package of MELCOR adopted CORCON/MOD3 model, this behavior resulted from the CORCON model. Originally, CORCON code developed for MCCI analysis and the phenomena without molten core-concrete interaction can not be correctly predicted. Nevertheless, in the case of the above correlation mixing, the MET temperature behavior follow the experimental value well.

As a future works, the followings will be studied for MELCOR1.8.6.

- Surface Heat flux Behavior
- Effect of Corium Composition Change
- Improve CAV package of MELCOR

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Table 1. SWICCS Test Series Specification

Parameter	1	2	3	**4**	5	6	7
Melt comp. (UO_2/ZrO_2/Cr /conc)	61/25/ 6/8	61/25/ 6/8	61/25/ 6/8	**61/25/ 6/8**	56/23/ 7/14	56/23/ 7/14	64/26/ 6/4
Concrete type	LCS	SIL	LCS	**LCS**	LCS	SIL	LCS
Melt mass (kg)	75	75	75	**60**	68	68	80
Init. melt T (°K)	~2300	~2100	~2100	**~2100**	~2100	~1950	~2100
Syst. press. (MPa)	0.1	0.1	0.4	**0.4**	0.4	0.1	0.4
Water Inj. (lpm)	4.0	4.0	12.0	**13.0**	6.0	14.0	13.0

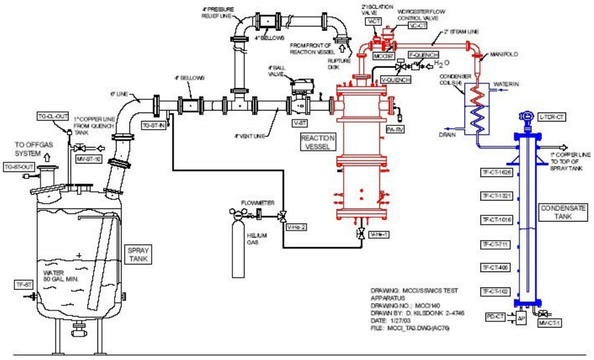

Figure 1. SWICCS Experiment Facility Diagram

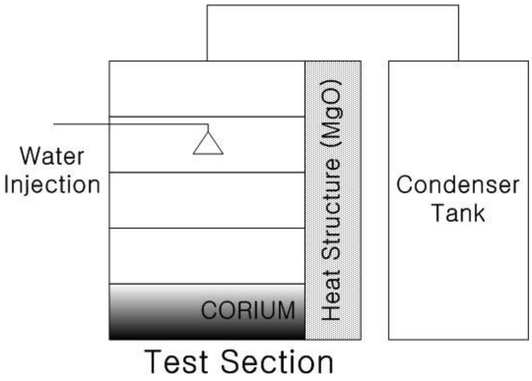

Figure 2. MELCOR Nodalization Diagram

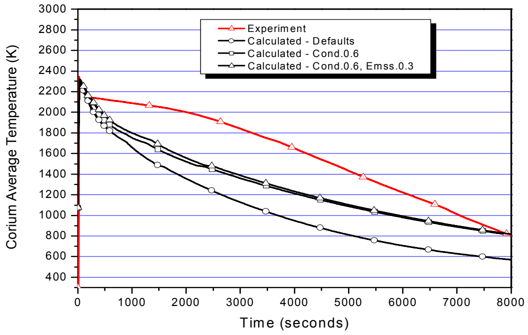

Figure 3. Corium Average Temperatures of Base and Sensitivity Cases

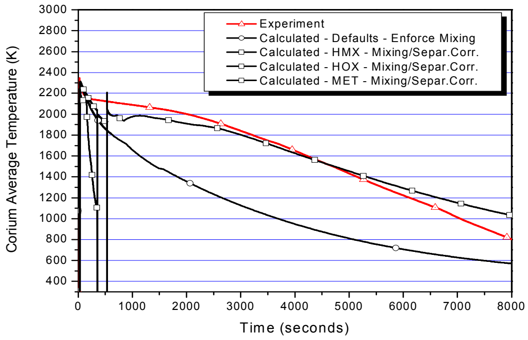

Figure 4. Corium Average Temperatures of Mixing Correlation Case