Application of MELCOR code to the MCCI analysis in Severe Accident Sequences

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1. Introduction

This paper illustrates the application of a severe accident analysis code, MELCOR [1], to the analysis of molten corium-concrete interaction (MCCI) phenomena in cases of severe accidents in nuclear power plants.

In postulated degraded core accidents, followed by the failure of certain engineered safety features of the reactor system, the reactor core may eventually melt owing to the generation of decay heat. If the safety features of the reactor system fail to arrest the accident within the reactor vessel, the corium (molten core debris) will fall into the reactor cavity and attack the concrete walls and floor. Basemat melt-through refers to the process of concrete decomposition and destruction associated with a corium melt interacting with the reactor cavity basemat. The potential hazard of MCCI is the integrity of the containment building owing to the possibility of a basemat melt-through, containment overpressurization by non-condensible gases, or the oxidation of combustible gases.

In the meantime, the MCCI still has large uncertainties in several phenomena such as melt spreading area, debris particulation, and heat transfer between the debris and cooling water. In particular, in the case where the water pool exists in the reactor cavity, research is ongoing because the uncertainty is very large for a heat transfer between the cavity corium and overlying water pool, or an axial and radial erosion ratio. Therefore, assumptions may be needed in the analysis of MCCI using the MELCOR code because currently the code cannot be said to provide an accurate model for the heat transfer from the corium into the overlying water pool, and the axial/radial erosion ratio. This paper provides some of the technical aspects that can be applied to an analysis of the MCCI phenomena in a severe accident scenario using the current MELCOR version.

2. MELCOR MCCI Model

The Cavity package is used to model the interactions between core debris and concrete in one or more locations in a MELCOR calculation; modeling is based on the CORCON-Mod3 code[2]. CORCON-Mod3 was designed for typical severe accident conditions early in the 1990s. The assumption in CORCON was that water cannot break up or penetrate the debris, and thus heat can only be removed from frozen debris by conduction to the surface. As a result (for typical compositions and internal heating rates) debris beds thicker than a few inches cannot be kept frozen. The cooling effects of the water ingress or gas bubble agitation are not considered. Fig. 1 and Fig. 2 compare the concrete erosion depth for the dry and wet cavity sample cases, where the erosion depths are almost same.

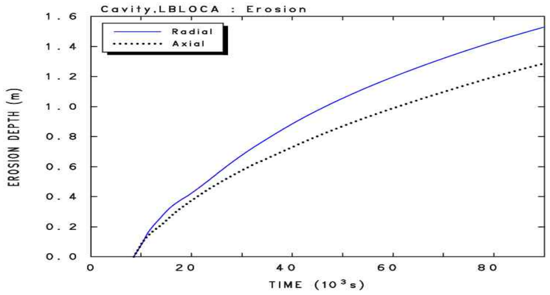

Fig. 1. Concrete erosion depth for a dry cavity

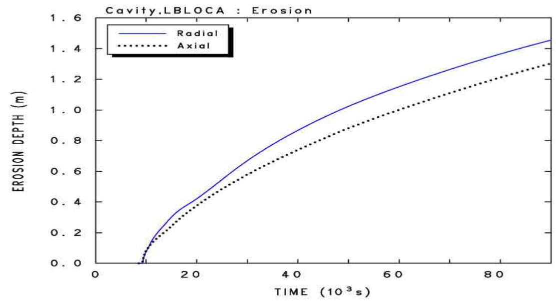

Fig. 2. Concrete erosion depth for a wet cavity

Recent beliefs about the enhanced conductivity at the upper surface owing to instability of the crust are handled very coarsely by adjusting the multipliers on the heat fluxes in late MELCOR version. In MELCOR 1.8.6, the user may promote quenching by increasing the values of the thermal conductivities used in the heat transfer calculation. It should be emphasized that this is a parametric control, not a model. However, even if the coefficients for a heat transfer between the debris and water can be increased through the use of the "Miscellaneous Control and Model Parameters" inputs with keywords BOILING, COND.OX, COND.MET, HTRINT, and HTRSIDE, this usually has an other limitation of the axial versus radial erosion rates owing to the independent heat transfer model in the axial and radial directions. MELCOR solves two independent 1-d heat transfer calculations in the axial and radial directions.

3. OECD MCCI Experiments

The OECD/MCCI Program [3] was carried out for the reactor material experiments and associated analyses to achieve the following two technical objectives: 1) resolve the ex-vessel debris coolability issue by providing both confirmatory evidence and test data for coolability mechanisms identified in previous integral effect tests, and 2) address remaining uncertainties related to long-term 2-D core-concrete interaction under both wet and dry cavity conditions.

Fig. 3 and Fig. 4 represent the experiment results of the heat flux from corium into the overlying water pool and the concrete erosion configuration of the axial versus radial erosion, respectively. Fig. 3 shows the debris/water heat fluxes ranging from 250 to 650 kW/m^2 after the initial transient. In addition, Fig. 4 shows an analogous erosion rate of axial versus radial erosion for the initial corium shape(dimension) of a regular hexahedron(cube) (for example, the reactor cavity sump shape).

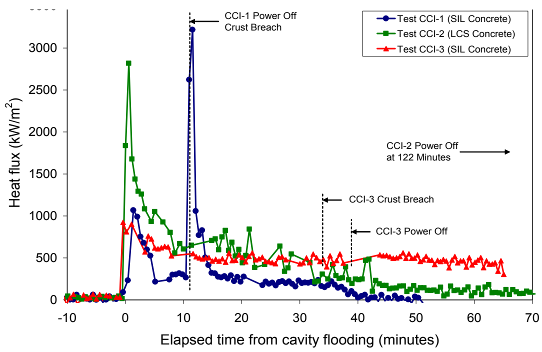

Fig. 3. Heat flux from debris into water (from OECD MCCI CCI Test[3])

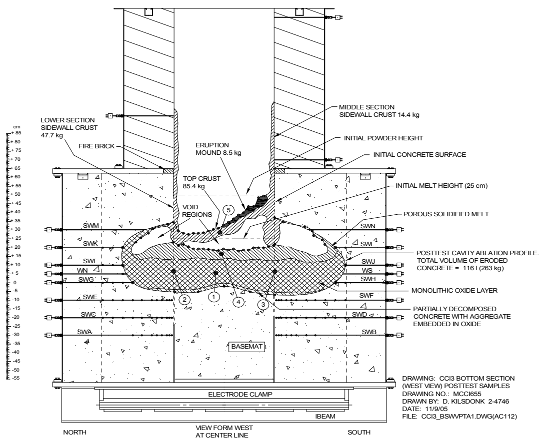

Fig. 4. Concrete erosion configuration (from OECD MCCI CCI-3 test[3])

4. Application Methodology

As mentioned above, the MCCI still has large uncertainties in several phenomena and the related MELCOR model is not accurate enough for the heat transfer from the corium into overlying water pool and the axial/radial erosion ratio. Therefore, it is a successful choice to assume the heat transfer rate from the corium into the overlying water pool and the axial/radial erosion ratio themselves based on the OE CD/MCCI Program.

For example, the following approach was carried out for the MCCI analysis of an APR-1400 plant: 1) two basic assumptions were set up for the heat transfer from the corium into the overlying water pool and the axial/radial erosion ratio, 2) the values of the model parameters were selected to satisfy the assumptions, and 3) an MCCI analysis was performed using the selected parameter values.

The two basic assumptions are: a) based on Fig. 3, the heat flux from corium into the overlying water pool is about 250-650 kW/m^2 considering water ingression into solidifying core material by the presence of gas sparging, and b) based on Fig. 4, the axial/radial erosions have an analogous erosion rate for the initial corium shape (dimension) of regular hexahedron (cube) which is similar to the corium configuration on the reactor cavity sump.

Various sensitivity studies were performed for the model parameters to obtain the basic two assumptions. However, it failed to reach the assumptions owing to the limitation of the heat transfer model. HTRINT is not applied in the uppermost layer of the layer stratification model and the forced mixing model which were employed in CORCON as debris layer models. One of the solutions is to modify the subroutine of CCHTOP.F, which make the model parameter of HTRINT work properly for the enforced mixing model. The basic assumptions were satisfied with the selected parameter set (BOILING=3, HTRINT=20, and HTRSIDE=10) using the modified subroutine, and finally the MCCI analysis was performed.

5. Conclusions

An application methodology of the MELCOR current version to the analysis of MCCI, the phenomena of which are very uncertain and lack specific knowledge during severe accidents, was introduced. Assumptions based on the experimental results are used instead of the phenomenological detail modeling because of the modeling limitations. In the technical aspects of MCCI, code modification itself is not a big deal, because the code modification is needed for just the user flexibility. The concern will be whether the assumptions made for this analysis are acceptable or not.

REFERENCES

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[3] M. T. Farmer, S. Lomperski, D. J. Kilsdonk, and R. W. Aeschlimann, OECD MCCI Project Final Report, OECD/MCCI-2005-TR06, February, 2006.