VVER-1000 Reflooding Scenario Simulation with MELCOR 1.8.6 Code in Comparison with MELCOR 1.8.3 Simulation

Jiří Duspiva
Nuclear Research Institute Řež, plc.
Nuclear Power and Safety Division
Dept. of Reactor Technology

The first NRI contribution to the QUENCH Workshop (5^{th} IQW in 1999) presented comparison of MELCOR 1.8.3 to ICARE2 V2-mod.2.3 for the reflooding scenario of the VVER-1000 reactor initiated with the large LOCA (200 mm). The aim of this simulation was the first scoping of the reflooding conditions and also the first estimation of consequences. The MELCOR 1.8.3 input model was prepared on the best practice level then, but in comparison with recent ones it was very simple. And also the phenomenological models in the MELCOR 1.8.3 code did not include several important features in a comparison with the MELCOR 1.8.6 version.

The activities related to the Quench test simulations started with the MELCOR 1.8.4 code in 2000. Own NRI input models for MELCOR 1.8.5 (with prereleased reflood model) and later for MELCOR 1.8.6 were developed. The NRI analyses cover the Quench-01, Quench-03 and Quench-06 with version MELCOR 1.8.5 (including reflood model), and Quench-01 and Quench-11 tests with the latest version MELCOR 1.8.6. The tests Quench-01 and Quench-06 are characteristic of the lower reflooding onset temperature (1900-2050 K), and the tests Quench-03 and Quench-11 have high reflooding onset temperature (> 2350 K) with the fast heat-up phase before reflooding.

Important mass of knowledge and also important code improvements are basis for the comparison analysis of the reflooding scenario with the old and recent versions of the MELCOR code. Because old results from the MELCOR 1.8.3 calculation are still available their comparison with the recent simulation results is very valuable possibility for evaluation of the progress done in 10 years period.

Three simulations with the MELCOR code are compared. The first one is original one performed with the MELCOR 1.8.3 PN version and relatively simple input model. Its simplicity is relative, because at time of its calculation it was standard practice, but in comparison with the recent input models it is really simple. The input model for the MELCOR 1.8.3 consists of 69 control volumes (5 of them model reactor pressure vessel), 60 nodes in COR package (12 axial levels in 5 rings), 106 flow paths, and 190 heat structures. The second simulation was performed with the latest release of the MELCOR code – MELCOR 1.8.6 YU_2911 and its input model represents standard approach to reactor applications with 7 control volumes describing reactor pressure vessel and total number of 129 ones for whole input file. It includes also 217 nodes in COR package (31 axial levels and 7 rings), 198 flow paths, and 379 heat structures. The third one was simulated with same version of the MELCOR code like the second one and the only difference of the input model is done by a very detailed subdivision of the core space into many control volumes (with one control volume per two COR nodes). This nodalization of the core space is very complicated, but it is recommended by the MELCOR developers as the recent best practice. The input file for the third simulation consists of 187 control volumes (65 of them are describing reactor pressure vessel) and 318 flow paths. Remaining numbers of input objects (COR package or heat structures) are unchanged in comparison with the second simulation and they are influenced only by a little different association to appropriate part of changed input deck.

All three simulations represent a scenario of severe accident which was terminated during the beginning phase of core degradation. The initiating event is a large break LOCA on surge line between hot leg and pressurizer with D_{eq} = 200 mm and subsequent event is a loss of all emergency core cooling systems together with a loss of 2 from 4 hydro-accumulators. The severe accident progression is terminated by core reflooding due to recovery of one of high pressure injection system in both (injection from water storage tank and recirculation from a sump) operation modes. This recovery was performed when the cladding maximum temperature was about 1200 K in the original simulation with the MELCOR 1.8.3, but the water supply to the core started a little later at time about 2420 s. The second and third simulation definitions were slightly modified to keep this time of a beginning of water supply into the core identical in all three simulations.

Result processing was focused mainly on comparison of an evolution of water level in core, temperature of cladding, hydrogen generation and also final configuration of the core. Some differences were observed in all three simulations, but the principal one was in unrealistically low hydrogen generation in the first one preformed with the MELCOR 1.8.3. It also predicted very quick successful quenching of core, but mainly very detailed modeling in the third simulation predicted very slow cooldown of the debris bed (with molten metals) in upper part of the core. This third prediction seems to be the most realistic also with a prediction of steam cavity in the area of that debris bed after practically full filling of core by water. Such effect cannot be simulated with the simplified one control volume per whole core input model. On other hand the penalty of the application of very detailed input used in the third simulation was very high consumption of CPU, several times higher then in the second simulation.

The answer on the coolability of such configuration is very difficult, because simulations with the MELCOR code resulted in prediction of success in the first and second ones, but the third one is very questionable concerning this topic. Finally, the answer can not be done based on these simulations, and one of reasons is that a total mass rate of high pressure injection system, which was recovered, is only 57 kg/s. That represents only about 1 g/(s – rod) of water, which is a limiting value for cooldown from maximum core temperature about 2200 K. But in these simulations the maximum core temperatures were significantly higher. So the final conclusion is that for a successful cooling is necessary to recover higher mass rate system or more trains of this low rate one.