MELCOR Code Assessment

1) Creation date of the summary: 22.06.2006

2) Record ID: 11444

3) Last update: 22.06.2006

4) Project status: Completed (01.08.2001 - 31.05.2006)

5) Organizational unit: Departement Maschinenbau und Verfahrenstechnik, direkt, Institut für Energietechnik, direkt, Kroger, Wolfgang, kroeger@mavt.ethz.ch, LZ=03292

6) Project leader(s):
- Chan, Sang Lung,

7) ETH researcher(s): no entry

8) External researcher(s): no entry

9) Funding source(s):
- Public institutions (e. g. federal offices)

10) Partner organizations: no entry

11) Short Summary: Co-operative research project with US NRC and HSK; code assessment/validation by benchmarking against SCDAP/RELAP5 and TMI-2 accident; creep rupture of vital components in the course of various accident scenarios

12) Keywords: Nuclear Engineering, Thermodynamics

MELCOR Code Assessment

13) Project description:

This co-operative research project between the US Nuclear Regulatory Commission (NRC), the Swiss Federal Nuclear Safety Inspectorate (HSK), and the Swiss Federal Institute of Technology Zurich – Laboratory for Safety Analysis (ETHZ-LSA) deals with the assessment and validation of the NRC severe accident code MELCOR. The goal is to assist the NRC (US Nuclear Regulatory Commission) in performing the assessments of its own code, the findings will be made available to the international community and be further used for the MELCOR code consolidation effort, which is the long-term goal of the NRC. The objectives of this co-operative project are as follows:
• It is intended to assist the NRC doing the code assessment and validation of MELCOR against SCDAP/RELAP5/MOD3.3 (S/R5/M3.3) in conjunction with the ongoing NRC MELCOR code consolidation.
• Those results could be presented in terms of code performance expectations for MELCOR.
• Make a recommendation to the NRC to implement the gap cooling model of the water ingression through the debris-to-vessel gap in MELCOR for the TMI-2 like accident.
• The results of the case studies for the TMI-2 accident scenarios may be useful to understanding, how well various modeling techniques for the lower head creep and heat transfer can simulate the TMI-2 benchmark;
• In particular, the functionalities of the S/R5/M3.3 models of molten pool and debris-to-vessel heat transfer are assessed with the TMI-2 base case accident sequences and particularly with the TMI-2 alternative accident sequence in which all coolant pumps and the high pressure injection are turned off after 6,000 s into the accident that has not been assessed for the S/R5/M3.3 until now.

The project will last for four years, from July-1-2001 to June-30-2005. An overview of the work accomplished is given below. It is noted here that the reports are preliminary and the conclusions do not necessary reflect NRC's view. After the June-30-2005, this project is extended until 31-May-2006.
1. Review of core package In MELCOR 1.8.5, - code consolidation issue - Made a review of the modeling of severe core degradation phenomena in MELCOR1.8.5 against SR5 Mod 3.3 (SCDAP/RELAP5 Mod.3.3).
2. MELCOR Probabilistic Risk Assessment (PRA) associated with improper dry cask loading conditions, such as higher decay heat, less He-filled, filled with wrong gas, and insufficient drying the cask, the effect of blocked vents and external fire issues. The time dependent temperature and pressure behaviors of the cask were evaluated. For the cases of loading the cask with higher decay spent nuclear fuel of 0.5 and 1.0 year cooling time, the steady state temperatures experienced by the cask is substantially higher. Hence, the risk of cask failure is considerable. The results will be used by NRC-PRA group to predict failure probability of dry storage casks under improper loading conditions and subsequent severe accident conditions [2.1].
3. Simulation of phase 2 of the Three Mile Island Unit 2 (TMI-2) accident scenario using MELCOR and SCDAP/RELAP5 - Investigated the in-vessel core damage progression of the accident, using the MELCOR TMI-2 input deck, which is limited only to phase 2 of the TMI-2 accident [3.1]. The report presents some simulation results of this phase 2 of the TMI-2 accident using the NRC-severe accident computer codes MELCOR 1.8.5-RE and SCDAP/RELAP5-Mod-3.3. These results will be compared with the available indirect TMI-2 data. Phase 2 of the TMI-2 accident extends from 100 minutes to 174 minutes after the loss of main feedwater.
4. Extensive simulation of modified phase 2 of the TMI-2 accident using SCDAP/RELAP5 and

MELCOR for code consolidation assessment - Considered modified phase 2 of the TMI-2 base case accident, e.g., the makeup/HPI flow rate of the base case of TMI-2 accident during phase 2 has been changed to include two test cases: 1 kg/s, and 2.5 kg/s. The simulations using makeup flow rates of 1 kg/s and 2.5 kg/s are calculated with MELCOR 1.8.5-RD4, MELCOR 1.8.5-RE, SR5 mod-3.3kn, SR5 mod-3.3kz, and SR5 mod3.3bf. The base case simulation is also performed [4.1], [4.2]. The results of these simulations were compared.

5. Lower Head Creep Rupture Failure Analysis Associated with Alternative Accident Sequences of the Three Mile Island Unit 2 - The objective of this analysis is to assess MELCOR 1.8.5-RG against SCDAP/RELAP5 MOD 3.3kz (SR5m33kz), and SCDAP/RELAP5 MOD 3.3bf (SR5m33bf). This lower head creep rupture analysis considers: (1) the Three Mile Island Unit 2 (TMI-2) alternative accident sequence-1, and (2) the TMI-2 alternative accident sequence-2. SCDAP/RELAP5 (SR5) model of the TMI-2 alternative accident sequence-1 includes the continuation of the base case of the TMI-2 accident with the reactor coolant pumps (RCP) tripped, and the High Pressure Injection System (HPIS) throttled after approximately 6000 s accident time. SCDAP/RELAP5 model of the TMI-2 alternative accident sequence-2 is derived from the TMI-2 base case accident by tripping the RCP after 6000 s, and the HPIS is reactivated after 12,012 s. MELCOR model of the TMI-2 alternative accident sequence-1 is based on MELCOR TMI-2 phase-2 model by tripping the RCP and throttling back the makeup flows to zero from 6000 s. In MELCOR model of the TMI-2 alternative accident sequence-2, the RCP are tripped from 6000 s and the constant makeup flow rate of 3.75 kg/s is activated from 6000 s. This makeup flow rate includes pump seal flow rate, but excludes the HPIS flow rate. The simulation is run until the lower head wall ruptures. In addition, the lower head penetration failure is also calculated with MELCOR for both TMI-2 alternative accident sequences. Lower head temperature contours calculated with SR5 are visualized and animated with open source visualization freeware ‘OpenDX’. Significant findings of the analysis include: (1) the TMI-2 lower head wall fails by creep rupture with either deactivations or activations of the HPIS; (2) for the TMI-2 alternative accident sequence-1, the time to creep rupture calculated with MELCOR 1.8.5-RG, SR5m33kz, and SR5m33bf agrees reasonably; (3) for the TMI-2 alternative accident sequence-1, the calculation with MELCOR predicts that the lower head wall failure occurred earlier than penetration failure, while MELCOR predicts the opposite for the TMI-2 alternative accident sequence-2; (4) for the TMI-2 alternative accident sequence-2, the calculation with MELCOR shows that when the lower head wall fails the temperature is 1810.9 K, which exceeds the melting temperature of 1789 K for carbon steel; (5) for both TMI-2 alternative accident sequences, calculations with both SR5m33kz and SR5m33bf indicate that different lower head wall locations fail rapidly one after another by a delay of a few seconds, while this is not the case for MELCOR. This analysis assumes that the debris is in perfect contact with the lower head wall, This is done in SR5 by setting the interfacial heat transfer coefficient between the debris and the lower head vessel wall to a value of 10,000 W/(m2.K). MELCOR does not model this interfacial heat transfer. This study considers only in-vessel phenomena. The results have been published in ICAPP ’04 [5.1], and ICONE12 [5.2].

(6) Simulations in the form of case studies for the TMI-2 accident scenarios are performed with the PC and UNIX version of S/R5/M3.3. It is aimed to assess the S/R5/MOD3.3 models of stratified molten pool and debris-to-vessel contact resistance [6.1] associated with the TMI-2 lower head creep rupture. The TMI-2 accident scenarios are studied in the following five cases.

Case 1: The TMI-2 base case accident is analyzed using the model of steady state natural convection in a well-mixed molten pool. It is assumed that the debris is in perfect contact with vessel wall, e.g. interfacial heat transfer coefficient is set to a value of 10,000 W/m2-K. It is noted here that the TMI-2 base case accident is divided into four distinct phases. Phase 1, from 0 to 6,000 s, is a small break loss of coolant accident through a stuck-open PORV with reactor coolant pumps (RCP) on; phase 2, from 6,000 s to 10,440 s, is the continuation of SBLOCA with RCP pumps off and the initiation of core heatup; phase 3, from 10,440 s to 12,000 s, is the pump transient at the B-loop with short term cooling effects; phase 4, from 12,000 s to 18,000 s, is the final stage of the accident with the reactivation of high-pressure safety injection System (HPI) and the relocation of approximately 20 metric tons of molten core materials to the core bypass and lower plenum.

Case 2: This TMI-2 base case accident is simulated using the S/R5/M3.3-model of natural convection in a well-mixed molten pool and debris-to-vessel contact resistance of 500 (W/m2-K) to simulate the imperfect contact of the debris with the lower head wall.

Case 3: This TMI-2 alternative accident sequence-1 is derived from the TMI-2 base case accident by tripping the RCP and the throttling the HPI after approximately 6,000 s accident time. It represents the scenario with the reactor vessel nearly dried out. S/R5 model of well-mixed molten pool is considered. It is assumed that the debris is in perfect contact with the lower head wall, e.g., heat transfer coefficient of 10,000 W/m2-K.

Case 4: This TMI-2 Alternative Accident Sequence-1 considers the S/R5/M3.3 models of a natural convection in a well-mixed molten pool and debris-to-vessel heat transfer coefficient of 500 W/m2-K to account for imperfect contact at the interface. The calculations are performed with a time step of 0.01 s (step 1) between 6,000 s and 10,440 s.

Case 5: This case is slightly different than Case 4 by using a different time step. The analyses of the TMI-2 alternative accident sequence-1 use the interfacial heat transfer coefficient of 500 W/m2-K to account for imperfect contact between the debris and vessel. A time step of 0.05 s (time step 2) is used within the accident time between 6,000 s and 10,440 s, to investigate the influences on some important parameters, such as the creep rupture time of the lower head, the hydrogen production etc. From these case studies, It is noted here that S/R5/M3.3 does not model the gap cooling of the lower head [6.2, 6.3] in which the cooling mechanism is explained by the water ingression through the gap between the debris and vessel wall. The results of these simulations clearly demonstrate that the TMI-2 lower head failure occurs. Thus solely, using the S/R5/M3.3 models of the molten pool and debris-to-vessel contact resistance, without implementing the gap cooling model, cannot explain the conservation of the TMI-2 lower head during the accident. These studies also conclude that the results calculated with the UNIX and Microsoft PC versions of S/R5/M3.3 are comparable and hydrogen productions as well as lower head creep ruptures vary with different time steps for the alternative accident sequence-1. Further, those results of the base case and alternative accident are alike, thus, the models cannot distinguish the base case from alternative accident scenarios.
The following assessments and developments should be considered in the near future:

- Further simulations with alternative TMI-2 accident sequences are necessary to ensure the capability of S/R5/M3.3 to properly model TMI-2 like accidents.
- The gap cooling module should be implemented in S/R5/M3.3 and MELCOR to model a cooling mechanism via water ingression through the gap between the debris and lower head wall, which may help to clarify the conservation of the TMI-2 lower head during the accident.

It is noted here at the time these simulations were performed, the only available input deck of MELCOR was modeled for the TMI-2 accident until phase 2. Therefore, the assessment of the complete TMI-2 accident scenario, from phase 1 to phase 4, can only be done with S/R5/M3.3

without MELCOR. The work of these case studies is accepted for a publication in 2006 in the ‘Nuclear Technology’ journal [6.4].

The Paul Sherrer Institute (PSI) has been assisting the Sandia National Laboratories (SNL) to develop a new input deck for the complete TMI-2 base case accident (from phase 1 to phase 4). SNL may make this input deck available to the USNRC in the near future. It is noted that MELCOR also does not have the gap heat transfer model. It is suggested to SNL to include this model in MELCOR. The PSI has obtained the new release MELCOR 1.8.6 which still cannot be compiled and executed properly as a run-capable MELCOR version. The PSI is waiting for the next release of MELCOR which will be programmed in FORTRAN 95, replacing FORTRAN IV.

References:
[2.1]. ‘Thermal Loads for Evaluating the Failure Probability of the HI-STORM 100 Cask under Severe Accident Conditions’, July 31, 2001. Jason H. Schaperow (NRC/SMSAB/DSARE)
[3.1] ‘TMI-2 Analysis Exercise’, Final Report, TMI-2 Joint Task Group, Principle Working Group No. 4, OECD-NEA
[4.1] RELAP5/MOD3.3Beta, NUREG/CR-5535/Rev 1-Vol IV, ‘RELAP5/MOD3.3Beta CODE MANUAL, VOLUME IV, MODELS AND CORRELATIONS’, prepared for the Office of Nuclear Regulatory Research, US NRC, Washington DC
[4.2] R. O. Gaunt et al,’Melcor 1.8.5 Simulation of TMI-2 Phase 2 with an enhanced 2-Dimensional In-Vessel Natural Circulation Model’, ICONE10-22321, Proc. of ICONE 10; April 14-18, 2002, Arlington, Virginia, USA

14) Popular description: no entry

15) Graphics: no entry

16) Publications: no entry

17) Links to important web pages: no entry