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# Calculation of The Core Damage & FP Release Behavior for The PHEBUS FPT0 Similar to Cold Leg Break Accident Using MELCOR

Jong-Hwa Park, Song-Won Cho and Hee-Dong Kim
Korea Atomic Energy Research Institute

## Abstract

This paper presents the analysis results for the core degradation processes and the fission product release of the PHEBUS FPT0 experiment using MELCOR1.8.3. The objective of this study is to assess models associated with the core damage and fission product behavior in MELCOR. The calculation results were much improved through sensitivity studies. Thermal/hydraulic behavior in the core and the circuit was well predicted under the intact core geometry. In non-eutectic model case, the $UO_2$ dissolution model in the MELCOR always showed such a tendency that the resulting dissolved $UO_2$ mass was small at the highly oxidized condition due to the model logic. Total $H_2$ generation mass was underpredicted because the stiffner was not modeled and the liner in the shroud was not allowed to be oxidized in MELCOR. Some difficulties were found in modeling the activation product were solved by manipulating the RN input associated with the initial fission product inventory. These problem were occurred because there are no control rod model in MELCOR. Generally the fission product release ratio showed a similar trend compared with the measured data except the activation product, which have no model to simulate in MELCOR.

## 1. Introduction

The PHEBUS FPT0 experiment, which was performed in Cadarache, France in 1993, is to study the phenomenology of severe accident sequence for which the fission product flow path involves the primary sides of the steam generator U tube and the containment building. The experimental scenario is characterized into four phases, the first is the bundle degradation phase and the second is the aerosol deposition phase in the containment under the isolated state by closing the connecting valve between the core and the containment. The third and fourth are the washing and chemistry phases. However, the aerosol deposition, washing and chemistry phases are not considered in this calculation. This calculation work focuses on only the melt progression and fission product release during the first phase (0.0 - 22000 sec). For the bundle analysis, time of control rod failure, initial time of oxidation escalation, amount of dissolved $UO_2$ pellet by molten Zircaloy, total amount of $H_2$ generation and damaged end state figure will be compared with the measured data. Also, the late phase of bundle degradation process such as the formation of the molten pool is investigated.

## 2. Input Modeling

MELCOR can simulate the control rod and other fuel rods as one rod representing mixed type. But in this study, the control rod and the fuel rod were modeled separately so as to evaluate the core model for predicting the control rod behavior, which is not considered in the MELCOR. It was assumed that the all the fuel pellets stand in their place after decladding. Therefore, declad pellet was not moved into the lower parts until each of their support plates failed. The intact fuel rod changes into a debris when the cladding temperature reaches over 2,098 K or when the unoxidized Zr cladding thickness reaches at less than 0.0001m. There are no heat generation from the debris condition. When the relocation starts, It was assumed that the dissolved $UO_2$ mass (as much as the fraction of 0.2 of the molten Zr mass) and all the $ZrO_2$ were relocated together with molten zircaloy. The core support plate and grid spacer remained in their place until their melting temperature was reached. The shroud has seven material layers initially[1]. But the interesting points would be the thermal behavior in the high temperature region. Therefore, it was assumed that the steam gap is kept closed over the calculation period. The shroud material properties have large uncertainty because there are no valid measured data. The rupture of the stainless steel cladding and fuel rod cladding was modeled to occur when the cladding temperature exceeds the users specified temperature (1,173 K). The gap release fraction was defined to 0.0 for the all radionuclide classes in this study because the nearly fresh fuel was used in this experiment. The some difficulties were found in modeling the activation product during simulating the control rod. This problem was occurred because there are no model to simulate the control rod specially in MELCOR. But this problem was solved by some manipulating the RN input associated with the initial fission product inventory. The core power was modeled using the table function in the COR package and the amount of decay heat generation due to the nine days irradiation was neglected. The initial inventories of the fission product and activation product in the core could be found from reference[2]. But the MELCOR do not differentiate the fission product and the activation product respectively. Therefore, all the fuel rods and control rods were treated with the fuel rod model. The fission product release from the core was calculated using the CORSOR-Booth model for the low burnup condition.

## 3. Sensitivity Studies and Calculation Results

### 3.1 Sensitivity Studies

In the base input deck (Case1), three main parameter were set as follows; The debris formation was allowed. The oxide layer could not hold up the molten mixture when the Zr melting temperature is reached. Further the vertical pipe and steam generator U tube was models as a single volume. Three sensitivity studies from CASE 2 to CASE 4 were performed and parameters were adjusted to well predict the PHEBUS FPT0 experimental scenario. The calculation results from the CASE 4 showed the good agreement compared with the experimental measured data.

#### 3.1.1 Debris Formation Criteria (CASE1 and CASE2)

In CASE1, it is assumed that the pellet debris is formed whenever the unoxidized Zr thickness reaches at the user specified limit value. In this case, most of the fuel rods are converted into the debris near the Zr melting temperature. As mentioned before, there are no heat generation from the debris in MELCOR. Therefore, fuel rod temperature could not be reached at high temperature (near the Zircaloy melting point) and $H_2$ generation mass was largely underpredicted [figure 1]. But in CASE2, it is considered that the decladed pellets were intact until the cladding is melting. The core and shroud thermal behavior of this case was more close to the measured data.

### 3.1.2 Nodalization of control volume (CASE 2 and CASE 3)

The second sensitivity study was performed to improve the gas temperatures in the vertical pipe and steam generator U tube CASE 2 shows that the gas temperature in the vertical pipe and steam generator U tube were largely overpredicted. This overprediction was resulted from use of the single volume for the components, where the gas temperature changes rapidly. It is more preferable that the vertical pipe and the steam generator U tube were divided into multi-control volumes. Consequently, the predicted gas temperatures in the circuits were more improved than that of CASE2 [Figure 2].

### 3.1.3 Model for the molten zircaloy hold up by oxide layer (CASE 3 and CASE 4)

In MELCOR code, Zircaloy claddings can not stand in their place over their melting temperature (2200K) in the default mode. But in reality, molten Zircaloy in the inside of the cladding may be hold up by the outer $ZrO_2$ layer. This phenomenon can be modeled as a sensitivity card in MELCOR[3]. It was assumed that the molten zircaloy would be relocated either when the cladding temperature exceeds the user-defined value (2500 K)or when the oxide thickness is less than user defined values (50% of the original cladding thickness). This study shows the different results for three parameters, i.e., $H_2$ generation mass, cladding relocation time and $UO_2$ dissolution mass. The hydrogen generation mass and cladding relocation time in CASE4 shows a good agreement with the measured data [Figure 3]. But the dissolved $UO_2$ mass for the CASE3 was became larger than that of CASE4. The main reason for this was attributed to the selection of the non mechanistic $UO_2$ dissolution model that the dissolved mass was determined only by the user specified fraction of existing molten zircaloy when the candling starts.

## 3.2 Calculation Results from the CASE4

Figure 4 shows that MELCOR code well predicts the evolution of temperatures of the control rod absorber material and guide tube at the level of 70cm, which was failed at about 11,920 seconds[4,5]. The Urbanic correlation well predicts the temperature increase rate for the rapid oxidation escalation time (above 1,853K). The calculated temperature at 80 cm was overpredicted between 12,000 and 12,300 seconds. This phenomena could be explained by the fuel relocation at this time. The relocation of the cladding of the outer ring was occurred at about 15,100 seconds for the three levels.

Other intact claddings were highly oxidized. No ceramic melting temperature (3123K) was reached. Total dissolved $UO_2$ mass was very small compared to the measured data.

From the calculated inside shroud temperature at 20cm, It can be deduced that a molten corium was relocated into this level about 15,100 seconds. The inside shroud temperature at 40cm was well predicted under the condition of intact outer fuel rod geometry. But all the inside shroud temperatures more than the 50, 60, 70cm were largely overpredicted after 15,100 seconds[Figure 5].

Total $H_2$ generation mass was about 80.0 g but the measured value was more than 90 g. This underprediction was occurred because the stiffner was not modeled and the liner was not allowed to be oxidized in MELCOR. In addition to these, it might be attributed to the under-estimation of the peak temperature in the high temperature range.

Vapor temperature in the SG U tube showed a different behavior depending on the steam flow rates. The vapor temperature in the top level of the SG U tube was not converged to the surface temperature(423 K). It was shown that the heat transfer between the gas and U tube structure was not sufficiently done. But the vapor temperature in the U tube near the G point dropped to the constant pipe surface temperature except the low steam flow rate state. The containment vapor temperature was largely underpredicted but the pressure behavior was very well predicted from this calculation [Figure 6]. This means that the gas mixture composition in the containment was not well modeled due to the lumped model in MELCOR. In real case, the humidity in the containment was varied depending on the locations in the containment [6]. However in this study, the humidity was considered as 100 percent throughout the containment. Figure 7 showed the end state core damage picture. Generally the fission product release ratio were well predicted except the activation product, which have no model to simulate in MELCOR[Figure 8].

## 4. Discussions and Conclusions

In case of choosing the rubble debris formation option, fuel temperature could not reach at high temperature (near Zr melting temperature). But this problem was solved by preventing the debris formation through the input parameter. Actually, the Zr melting temperature is not sufficient to completely oxidize all the zircaloy by the steam. Therefore, to avoid relocation of the cladding at Zr melting temperature, a molten zircaloy hold up model by oxide layer was used. The under-prediction of the dissolved $UO_2$ mass was occurred due to the selected dissolution model logic. In non-eutectic model case, the $UO_2$ dissolution model in the MELCOR always showed a tendency, which the resulting dissolved $UO_2$ mass should be small in the highly oxidized condition. For the future, 'Eutectic' model is needed to be evaluated. The molten pool formation from the relocated rubble debris or corium mixtures in the lower part could not be simulated due to the following two reasons. The first is that the heat generation from debris is not allowed in MELCOR. The second is that the redistribution of the decay heat by the fuel relocation can be tracked in MELCOR but the amount of simulated decay heat was negligible in this study. In case of simulating the experiment like this, the core power was increased or decrease during the test but actually the decay heat always decrease versus time. Therefore molten pool formation from the rubble debris could not be simulated in this study. Total $H_2$ generation mass was underpredicted because the stiffner was not taken into account and the liner was not allowed to be oxidized in MELCOR. If the stiffner is oxidized completely, then 12.5 g of $H_2$ can be generated. The vapor temperatures in the vertical pipe, steam generator U tubes were overpredicted due to the lumped model in MELCOR. But this problem could be improved using multi-volumes. Some difficulties were experienced in modeling the activation product during simulation of the control rod. This problem was occurred because there are no model to simulate the control rod specially in MELCOR. Negative sign of the uranium mass was occurred because there are no control rod model to treat the activation product separately. The gap release fraction was specified as 0.0 since there were no significant gap release at the early part of the test because the nearly fresh fuel was used. Generally the fission product release ratio showed a similar trend compared with the measured data except the activation product, which have no model to simulate in MELCOR.

## 5. Reference

1. I. Shepherd, F.Serre and G. Repetto, "Specification for bundle scoping calculations for the reference scenario of PHEBUS Test FPT-0", JRC & CEA, August 1992.
2. 'PHEBUS PF-FPT0 Test Preliminary Report - ADDENDA', JRC, Dec 1994.
3. MELCOR1.8.3 Reference manual and User's guide, Vol 1-4, SNL, July 1994.
4. " PHEBUS PF FPT0 Test Preliminary Report and compilation of figures", JRC, May 1994.
5. Measured data Tape from Cadarache, 1993.
6. I.Shepherd, L.Herranz etc, "Pre-Test Calculation for the Thermal/hydraulic Tests carried out in the PHEBUS-FP Containment Vessel", JRC, 1994.

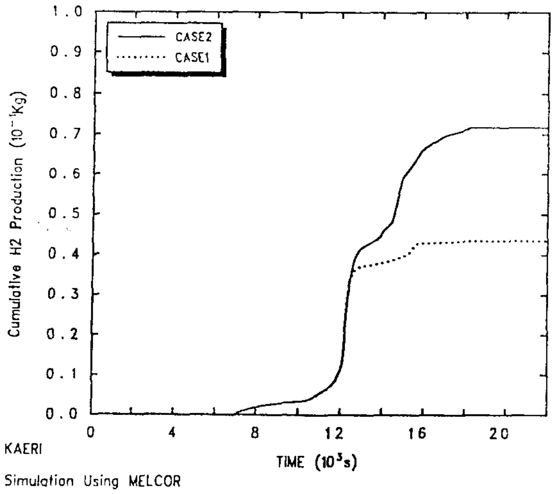


Figure 1 Total H2 Generation Mass (CASE1 / CASE2)

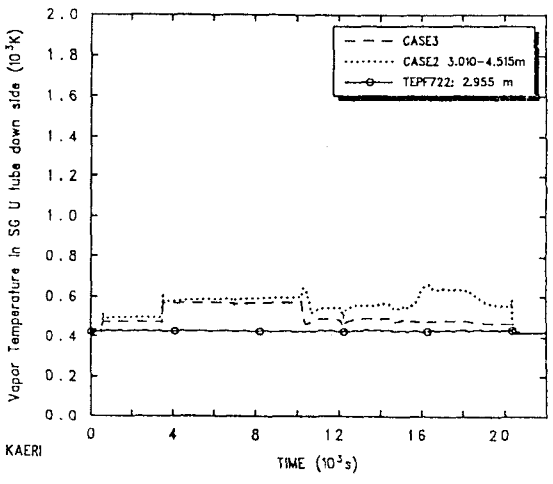


Figure 2 Vapour Temperature in SG U tube down side (CASE2/CASE3)

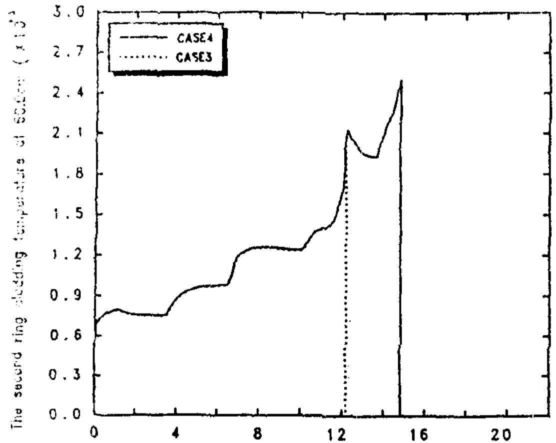
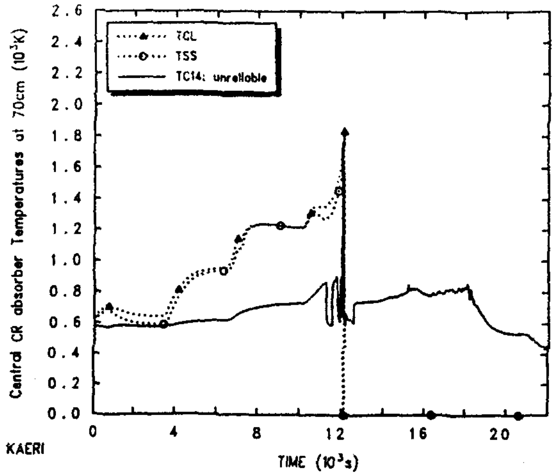


Figure 3 Second Ring Cladding Temperature at 60 cm (CASE3 / CASE4)



Simulation Using MELCOR

Figure 4 Center CR Absorber Temperature at 70 cm (CASE4)

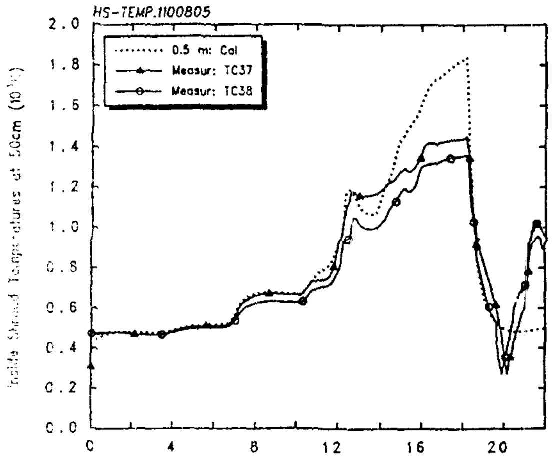
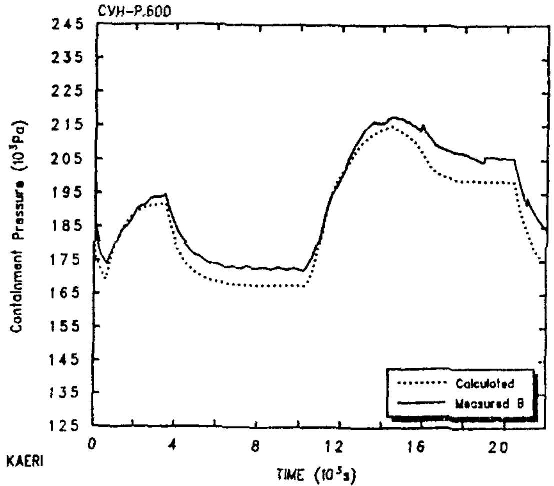


Figure 5 Inside Shroud Temperature Behaviour at 50cm (CASE4)



*Phebus FPT-0*

Figure 6 Containment Pressure Evolution (CASE4)

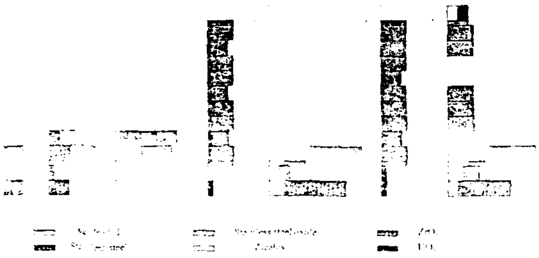


Figure 7 Core Damage End State Picture at 22000 sec

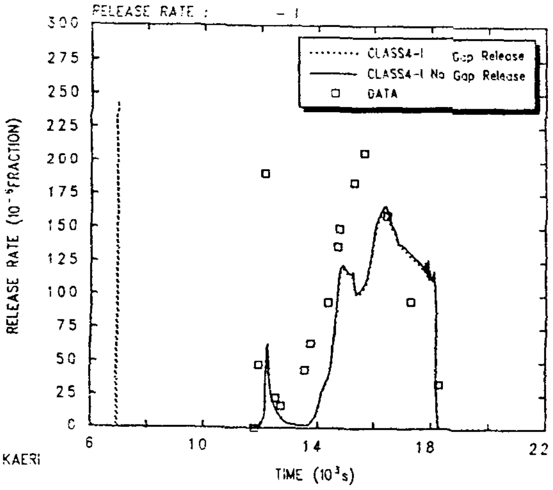


Figure 8 Iodine Release Ratio (Gap release/ No-gap release: CASE4)