MELCOR Sensitivity Analysis Focusing on the Heat Source

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1. Introduction

For the management of spent fuel pool (SFP) accidents, an exact understanding on accident progress is required. In the present study, an effect of heat source on a cladding temperature escalation was extensively investigated by a severe nuclear accident code, MELCOR-SFP version. Present study conducted MELCOR code calculation by assuming the situation of complete loss of coolant accident (LOCA) scenario in a PWR 17 x 17 single spent fuel assembly, not an overall spent fuel pool..

2. Background of MELCOR code calculation

On the normal operation of spent fuel pool cooling system, temperature would be relatively low and spent fuel assembly would be submerged in the coolant so there might be no rapid oxidation reaction on the cladding material. In this assumed normal condition, decay heat would be a main heat source.

However, in the complete LOCA accident scenario spent fuel assembly could be only cooled by air so the released heat might not be effectively transferred to an environment and the residual heat would be accumulated in the spent fuel assembly by a decay of nuclear fission products.

If this decay heat would be accumulated at a certain point, cladding temperature might increase to initiate a rapid oxidation reaction between Zr-alloy cladding and air.. Through an exothermic heat release from the oxidation of Zr-alloy by air, the cladding would be experience a very sharp temperature increase that was observed during the Sandia Fuel Project Phase-1 experiment (reference please: SNL report). This markedly sharp temperature escalation initiated a fire in the fuel assembly. Present study focused on the phenomenon of zirconium fire during the SFP complete LOCA scenario.

2.1 Decay Heat

First, based on the PWR 17 x 17 spent fuel decay heat measurement data of Swedish CLAB spent fuel storage facility [1], 0.3 kW – 1.0 kW range (0.1 kW step) of decay heat was considered.

Secondary, to compare the MELCOR analysis result with those of another research group, 5.0 kW – 20.0 kW range (5.0 kW step) of decay heat was considered.

In addition, in order to check the detail about zirconium fire, 1.0 kW – 5.0 kW range (1.0 kW step, including 4.5kW) of decay heat was also considered.

2.2 Oxidation Heat

Oxidation coefficients of five different research group were used (AEKI, ANL, IRSN, KIT, NUREG).
In the oxidation model implemented on the MELCOR, the growth of the oxide scale should be inversely proportional to present thickness of an oxide scale.

$$\frac{d(\Delta\delta)}{dt} = \frac{k_i}{\Delta\delta} \quad (1)$$

k_i in the equation (1) could be expressed by following equation (2), Arrhenius equation

$$k_i = A_i e^{-E_{a_i}/(RT)} \quad (2)$$

According to the Table I, pre-exponential factor A_i and activation energy E_{a_i} is different by each research group.

Table I: Oxidation Coefficient used in MELCOR analysis

Research Group	A_i ($kg_{zr}^n/m^{2n}/s$)	Ea_i (K)	Temperature Range (K)
AEKI	21.72 10^4	29054	∀ T
ANL Pre-breakaway (pre-oxidized cladding)	26.82	17490	∀ T
ANL Post-breakaway (pre-oxidized cladding)	2982.27	19680	∀ T
IRSN	2.27 10^4	23442	∀ T
KIT	9.691 10^2 7.741	20890 9687	973 < T < 1173 1373 < T < 1673
NUREG	10.50 25.11 10^4 50.40	15630 28485 14634	T < 1333 1333 ≤ T ≤ 1550 1550 < T

2.3 MELCOR Input Configuration

This study improves the MELCOR input of Sandia National Laboratory with many errors. Fig. 1 describes that the nodalization of MELCOR input improved by this study.

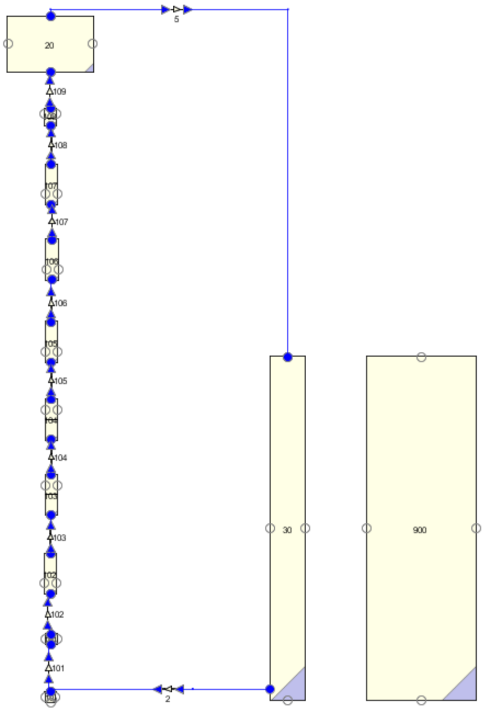

Fig. 1. SFP MELCOR nodalization input

3. Result & Discussion

MELCOR analysis was conducted by varying oxidation coefficients derived by five different research group and 0.3kW – 20.0kW range of decay heat.

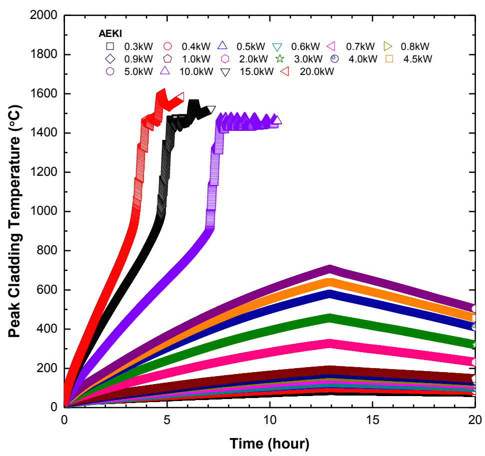

Fig. 2. MELCOR analysis result using oxidation coefficient of AEKI (0.3kW – 20.0kW decay heat)

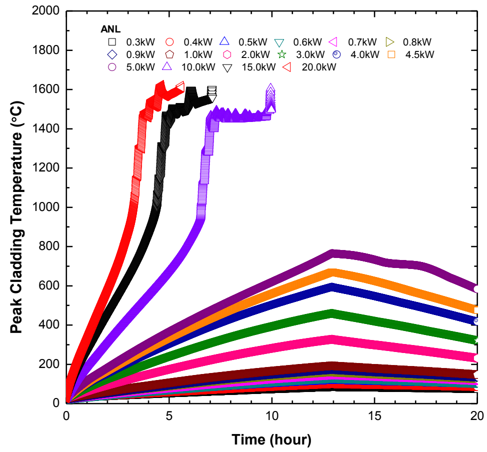

Fig. 3. MELCOR analysis result using oxidation coefficient of ANL (0.3kW – 20.0kW decay heat)

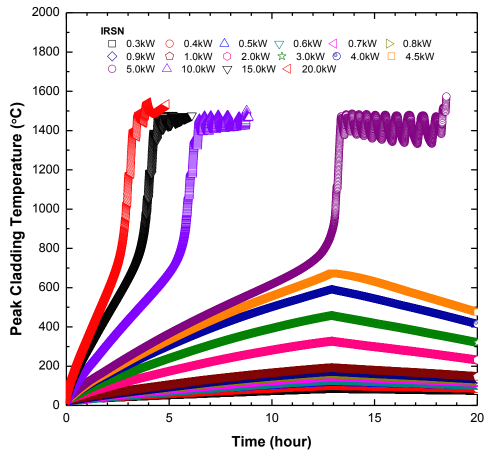

Fig. 4. MELCOR analysis result using oxidation coefficient of IRSN (0.3kW – 20.0kW decay heat)

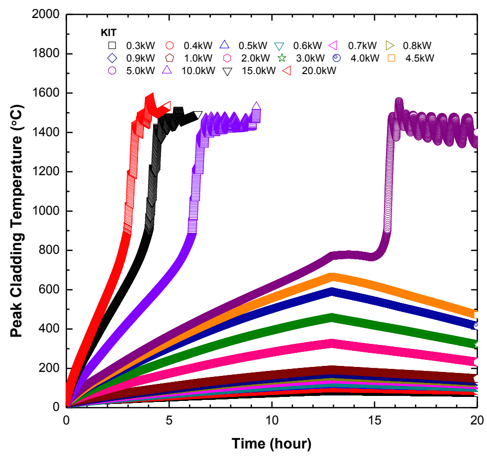

Fig. 5. MELCOR analysis result using oxidation coefficient of KIT (0.3kW – 20.0kW decay heat)

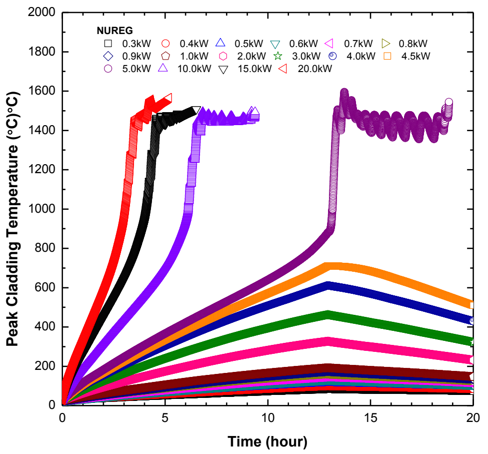

Fig. 6. MELCOR analysis result using oxidation coefficient of NUREG (0.3kW – 20.0kW decay heat)

From the MELCOR analysis result, peak cladding temperature of the spent fuel assembly in the situation of complete LOCA was analyzed. According to the magnitude of the decay heat and oxidation coefficients of five different research groups, trend of cladding temperature shows some differences.

By increasing the magnitude of the decay heat and it reached to certain value, peak cladding temperature suddenly increased deviating from the initial trend. This phenomena is called zirconium fire. Because the difference in the oxidation coefficient on the MELCOR simulation, an existence of zirconium fire at certain value of decay heat and the times when the zirconium fire occur were different.

In the case of using the oxidation coefficient of AEKI and ANL, zirconium fire occurred at the range of decay heat between 5.0 kW and 10.0 kW. However, in the case of using the oxidation coefficient of IRSN, KIT and NUREG, zirconium fire occurred at the range of decay heat between 4.5 kW and 5.0 kW.

Evaluating the time when the zirconium fire occurred, if the decay heat is larger than 10.0 kW, initiating times of zirconium fire for cases of using different oxidation coefficients were similar. At the case using the oxidation coefficient of AEKI, initiating time of zirconium fire is about 7 hours, but in other cases it is observed that zirconium fire initiated at 6 hours (Fig. 10). Moreover, when the decay heat were 15.0 kW and 20.0 kW, ranges of initiation time of the zirconium fire were 4-5 hours and 3-4 hours. At the range of decay heat larger than 10.0 kW, initiating times of the zirconium fire were similar not much affect by difference on the oxidation coefficient.

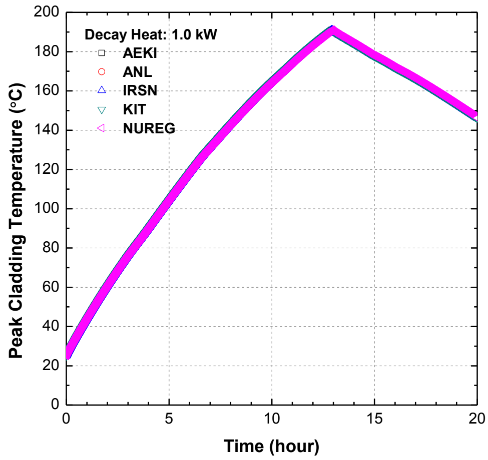

Fig. 7. MELCOR analysis result of all oxidation coefficients (decay heat: 1.0 kW)

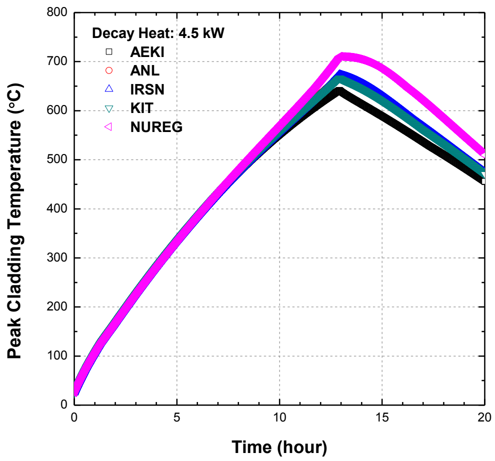

Fig. 8. MELCOR analysis result of all oxidation coefficients (decay heat: 4.5 kW)

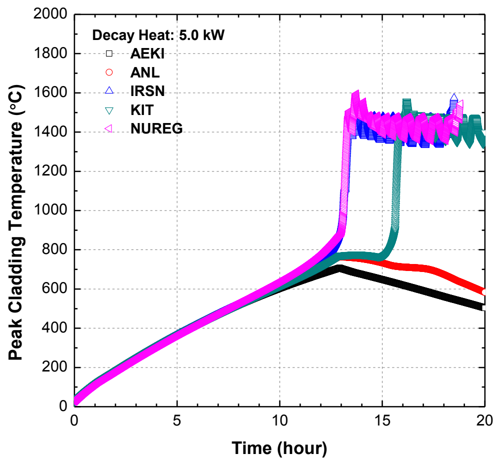

Fig. 9. MELCOR analysis result of all oxidation coefficients (decay heat: 5.0 kW)

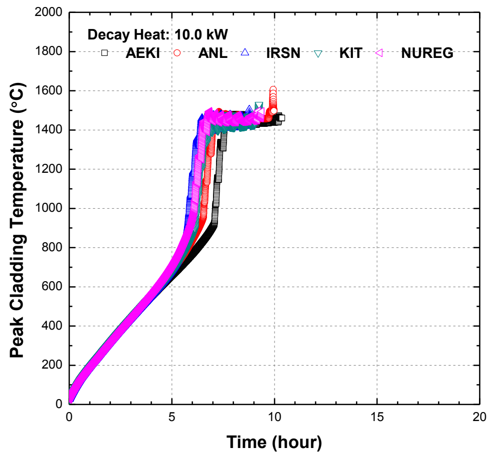

Fig. 10. MELCOR analysis result of all oxidation coefficients (decay heat: 10.0 kW)

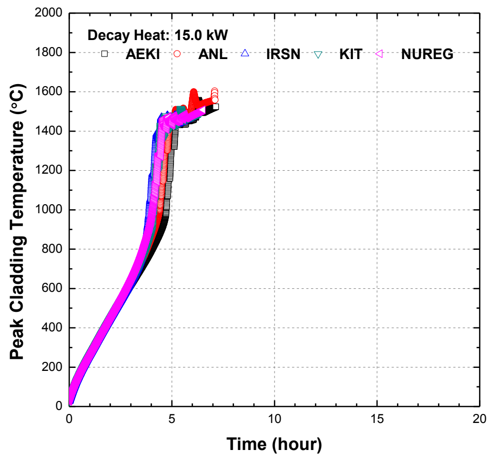

Fig. 11. MELCOR analysis result of all oxidation coefficients (decay heat: 15.0 kW)

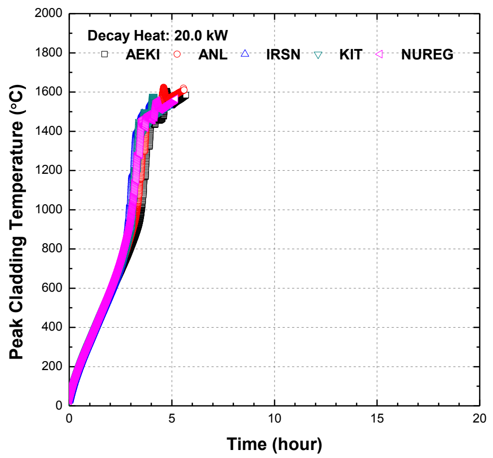

Fig. 12. MELCOR analysis result of all oxidation coefficients (decay heat: 20.0 kW)

From the result of MELCOR analysis, the oxide coefficient shows high sensitivity at intermediate range of decay heat. As shown on the Fig. 7 to Fig. 12, MELCOR simulation results of peak cladding temperature show a little difference especially on the Fig. 8, Fig. 9 and Fig. 10.

In addition, these disagreements between MELCOR simulation results seem to be distributed on the temperature range from about 700℃ to about 1400℃.

Therefore, additional experiment and the revision of oxidation coefficient is necessary at the temperature range from about 700℃ to about 1400℃.

4. Conclusion

Present study conducted MELCOR analysis focusing on the heat source (decay heat, oxidation heat) and analysis object was PWR 17x17 spent nuclear fuel assembly. By changing the decay heat and oxidation coefficient, variation of peak cladding temperature to the time of the fuel assembly was analyzed. Different oxidation coefficient results the difference on the initiating time and existence of zirconium fire.

From the result of MELCOR analysis, we found the criteria of decay heat that MELCOR simulation result showed the disagreement of peak cladding temperature, about 5.0 kW – 10.0 kW range. This disagreement could be resulted from the uncertainty between research groups. Therefore further study is necessary.

ACKNWOLEDGEMENT

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[1] B. D. Murphy, I. C. Gauld, NUREG/CR-6971 ORNL/TM-2008/016, Spent Fuel Decay Heat Measurements Performed at the Swedish Central Interim Storage Facility, Oak Ridge National Laboratory, February 2010.