Sensitivity Study of Calculation for FLECHT-SEASET Tests Using MARS Code

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1. Introduction

MARS code is a realistic multi-dimensional thermal hydraulic systems code developed by the Korea Atomic Energy Research Institute (KAERI) based on RELAP5 and COBRA-TF codes and is used to analyze the behavior of light water reactor transient. MARS code can quite accurately calculate the trend of fuel rod temperature changes in FLECHT-SEASET tests, especially at low mid-plane locations. However, the peak cladding temperatures calculated by MARS code was lower than peak cladding temperature (PCT) measured by FLECHT-SEASET tests and the quenching time (QT) was shorter.

There are two main ways to improve the capability of MARS code in analyzing reflood phenomena: using better models in the source code or performing a sensitivity study to reduce user effect errors. The current paper presents a sensitivity study that was done to improve the capability of the MARS code in calculating reflood phenomena through assessment of FLECHT- SEASET tests.

2. Reflooding Phenomena and FLECHT-SEASET Tests

2.1 Reflooding Phenomena

Reflooding phenomena occur in the loss of coolant accident after the core has been uncovered and then emergency core cooling system inject water to refill the core. When the water level of the core increases, water will contact with hot fuel rod and steam formed. However, the fuel rods are not cooling down uniformly then many of heat transfer regimes exists in reflooding phase as presented in the Figure 1. Figure 1 also show the different in heat transfer and hydraulic flow regimes in reflooding phase between low and high flooding rate.

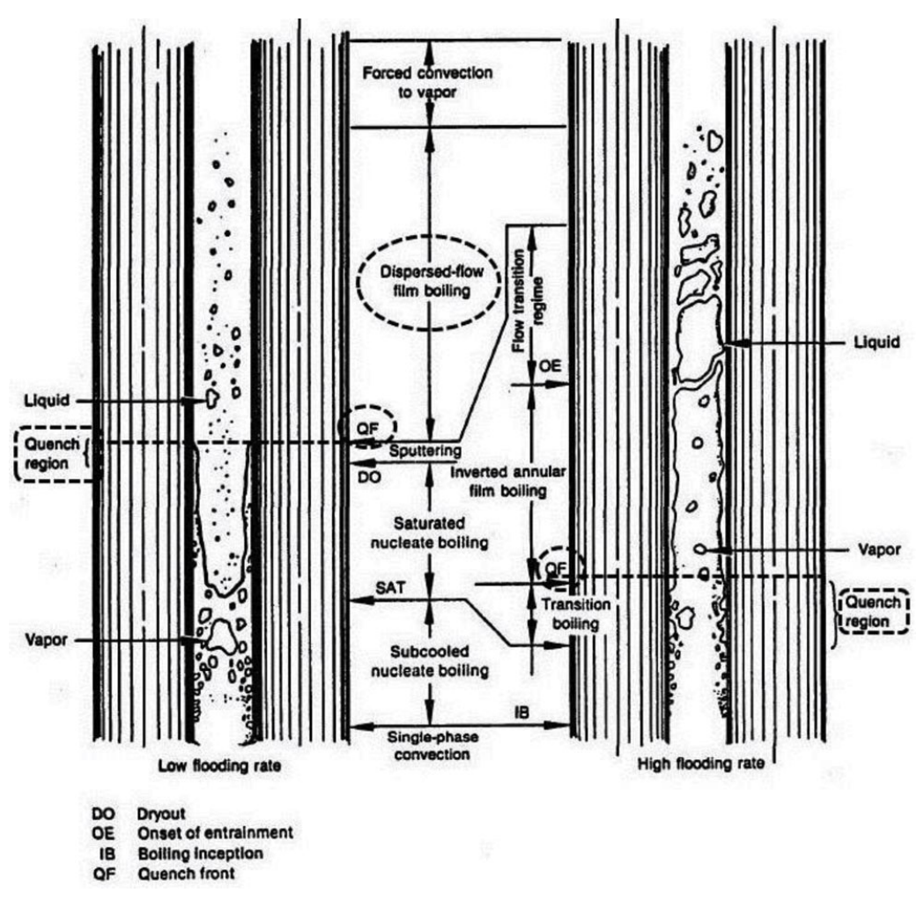

Figure 1. Heat transfer and hydraulic flow regimes in reflooding phase.

2.2 FLECHT-SEASET Tests

FLECHT-SEASET is forced reflood test facility. It used electrically heated rod to simulated a full length Westinghouse 17 x 17 rod bundle. The main component of FLECHT-SEASET is a test section which consisted lower and upper plenum connected to a cylindrical with diameter 3.89 m. The initial average power of FLECHT-SEASET is 2.3 kW/m. Table 1 presents some main FLECHT-SEASET tests for reflooding. Three tests were selected for this sensitivity study.

Table 1. FLECHT-SEASET tests conditions.

Test No.	Upper Plenum pressure (MPa)	Reflood flow velocity (mm/sec)	Coolant temperature (°C)
31805	0.28	21	51
31504	0.28	24.6	51
31203	0.28	38.4	52
31302	0.28	76.5	52
31701	0.28	155	53
31108	0.13	79	33
32013	0.41	26.4	66
32114	0.28	25 to 31	125

3. Input modeling and Nodalization

Figure 2 presents the nodalization used in FLECHT-SEASET tests calculation by MARS code. The reflooding coolant temperature and velocity was simulated through TMDP VOL 100 and TMDP JUN 150, respectively. The test section part was simulated by PIPE 200 with 20 nodes or 49 nodes depending on study cases. The upper plenum pressure was simulated through TMDP VOL 300. Five heat structures (HS 2001, HS 2002, HS 2003, HS 2004 and HS 2005) simulated for fuel rods, housing structure, thimbles, filter and failed rods, respectively.

The initial axial temperatures of fuel rods, failed rods and housing was considered by setting initial temperatures of each heat structures. The effects of the spacer grids were also considered in this sensitivity study. However, there are some fluctuations of reflooding flow velocity and coolant temperature in experiment but the values were simulated by nominal values of temperature and velocity.

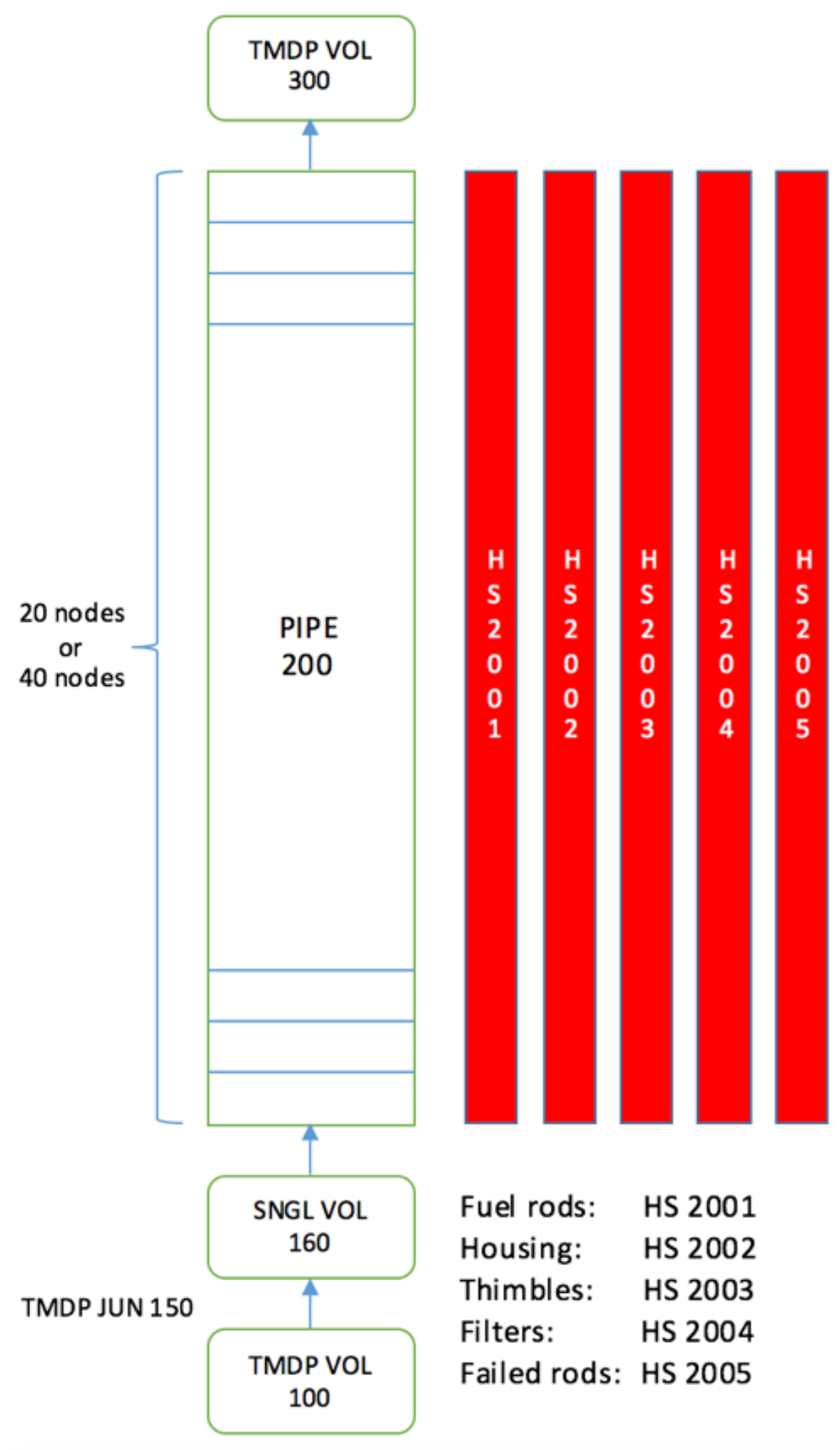

Figure 2. MARS code nodalization of FLECHT-SEASET.

4. Sensitivity Study

To cover for both low and high reflooding flow velocity, Test 31504, Test 31805 and Test 31701 were selected for sensitivity study.

Table 2 shows the matrix cases analyzed in this sensitivity study. For each sensitivity studies case, the peak cladding temperature and the quenching time were taken into account at each 2 feet, 6 feet and 10 feet locations; which locations correspond to low, middle and high locations along axial fuel rod.

Table 2. Sensitivity study matrix cases.

Sensitivity study cases	Test No.		
	31504	31701	31805
Number of axial nodes	x	x	
Spacer grids modeling	x		x
Maximum time step	x		
Option 40[1]	x	x	x
Lower plenum modeling[2]	x		x
Housing HS modeling	x	x	

1: KINS reflood model heat transfer correlations [6]

2: Modeling by single volume 160 in nodalization

5. Results and Discussion

To study effect of nodding to PCT and QT in FLECHT-SEASET tests calculation by MARS code, Test 31504 and Test 31701 was analyzed in both 20 nodes and 49 nodes calculations respectively. The analysis results showed large effect of number of nodes to the peak cladding temperature and the quenching time in FLECHT-SEASET tests calculations; the results also presented less effective on number of nodes at high reflood flow velocity.

Figure 3 and Figure 4 present the cladding temperature at 6 feet location of Test 31504 and Test 31701. At 6 feet, PCT and QT of Test 31504 was 1351.5 K and 284 seconds in 20 nodes calculation, while they were changed to 1337.9 K and 222 seconds in 49 nodes calculation; The PCT and QT of Test 31701 at the same location was 1137.4 K and 70 seconds in 20 nodes calculation changed to 1132.4 K and 64 seconds in 49 nodes calculation.

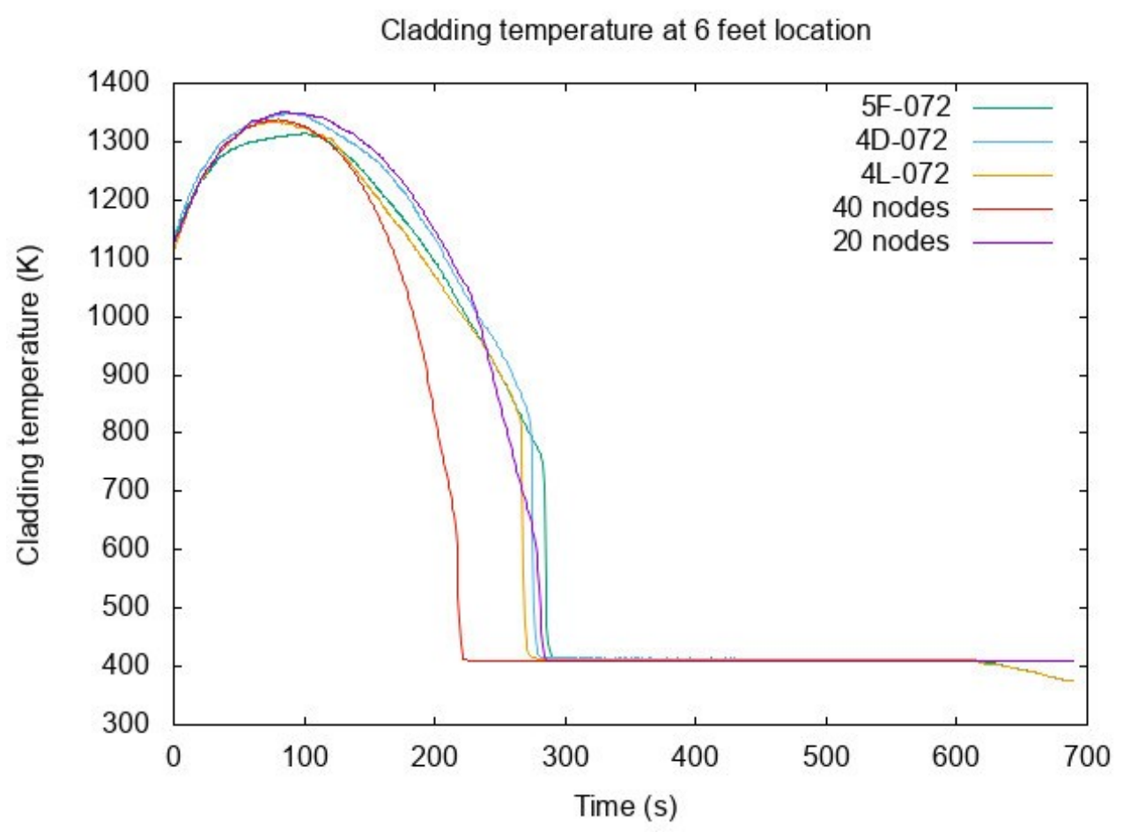

Figure 3. Cladding temperature at 6 feet location of test 31504

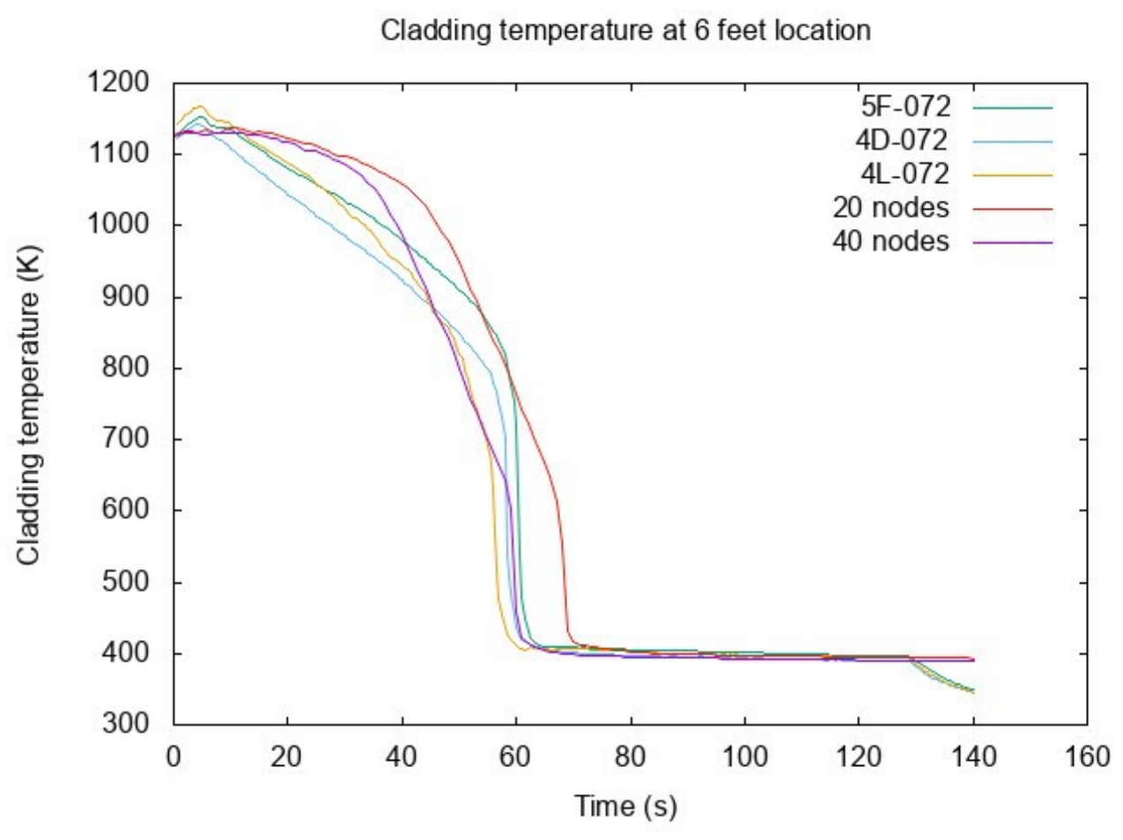

Figure 4. Cladding temperature at 6 feet location of test 31701

The PCTs and QTs results from sensitivity study for with- and without-grids modelling are shown in Table 3. By taking into account spacer grids effect, it will increase the peak cladding temperature and the quenching time, especially at middle location in lower reflood flow velocity cases.

Table 3. PCTs and QTs calculated in cases of with and without spacer grids modelling.

	PCT (K)			QT (s)		
	2 ft	6 ft	10 ft	2 ft	6 ft	10 ft
Test 31504						
with grid	720.7	1337.9	1053.7	33	222	512
w/o grid	720.8	1331.7	1043.8	35	230	492
Test 31805						
with grid	728.4	1369.9	1104.0	37	250	553
w/o grid	728.4	1363.1	1093.5	38	256	552

The PCTs and QTs were not affected by the maximum time step input as shown in Table 4.

Table 4. PCTs and QTs calculated in cases of 0.1 seconds and 0.001 seconds maximum time step.

	PCT (K)			QT (s)		
	2 ft	6 ft	10 ft	2 ft	6 ft	10 ft
Test 31504						
0.1 s	720.7	1337.9	1053.7	33	222	512
0.001 s	721.0	1337.9	1053.9	32	220	515

The effect of lower plenum modeling or not modeling also was not large to PCTs and QTs calculation.

The developer option 40 was most effective to PCTs and QTs results as shown in Figure 5. By turning on developer option 40, the peak cladding temperature was increased and the quenching times was delayed in all calculated tests. The developer option 40 was more effective in lower reflood flow velocity cases since the quenching time was delayed in this cases.

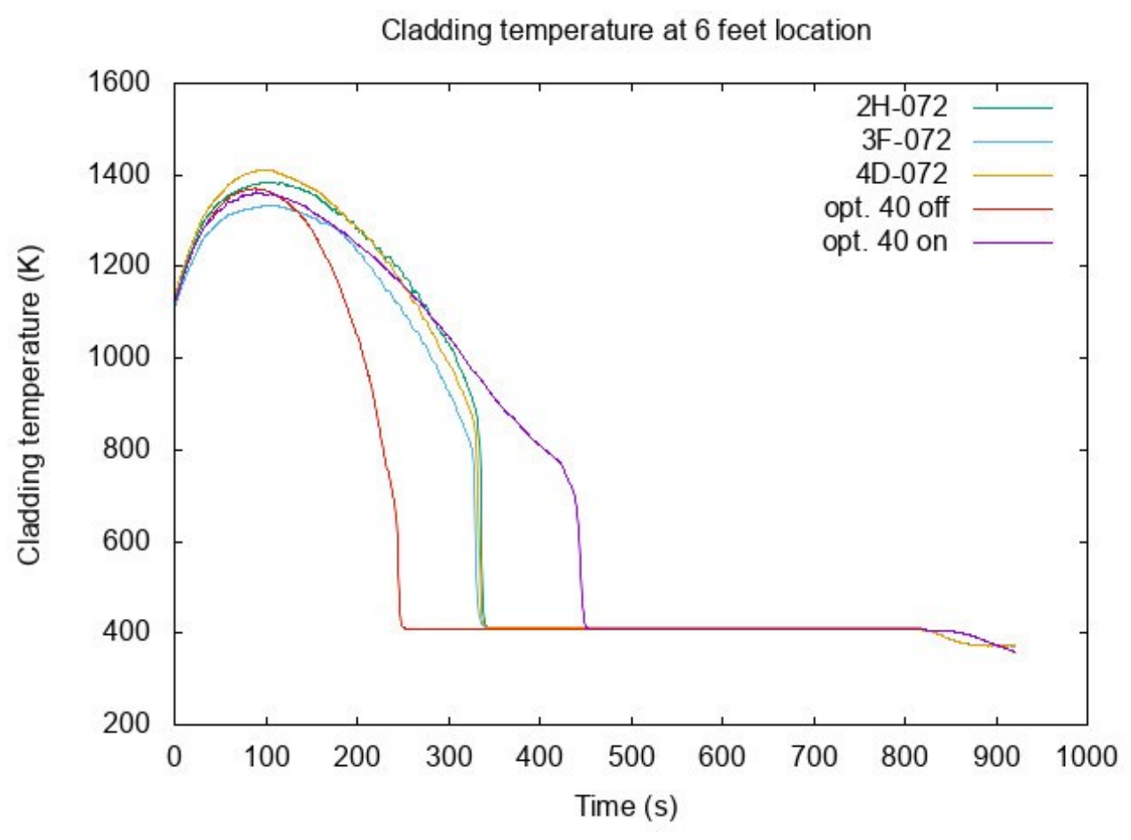

Figure 5. Cladding temperature at 6 feet location of test 31805

Due to simulation of housing structure modelling, the heat loss from system was taken into account then results were more accurate than without modelling. As observed in Table 5 and Figure 6, modelling of heat sink structure like the housing was very important in calculation of reflood phenomena.

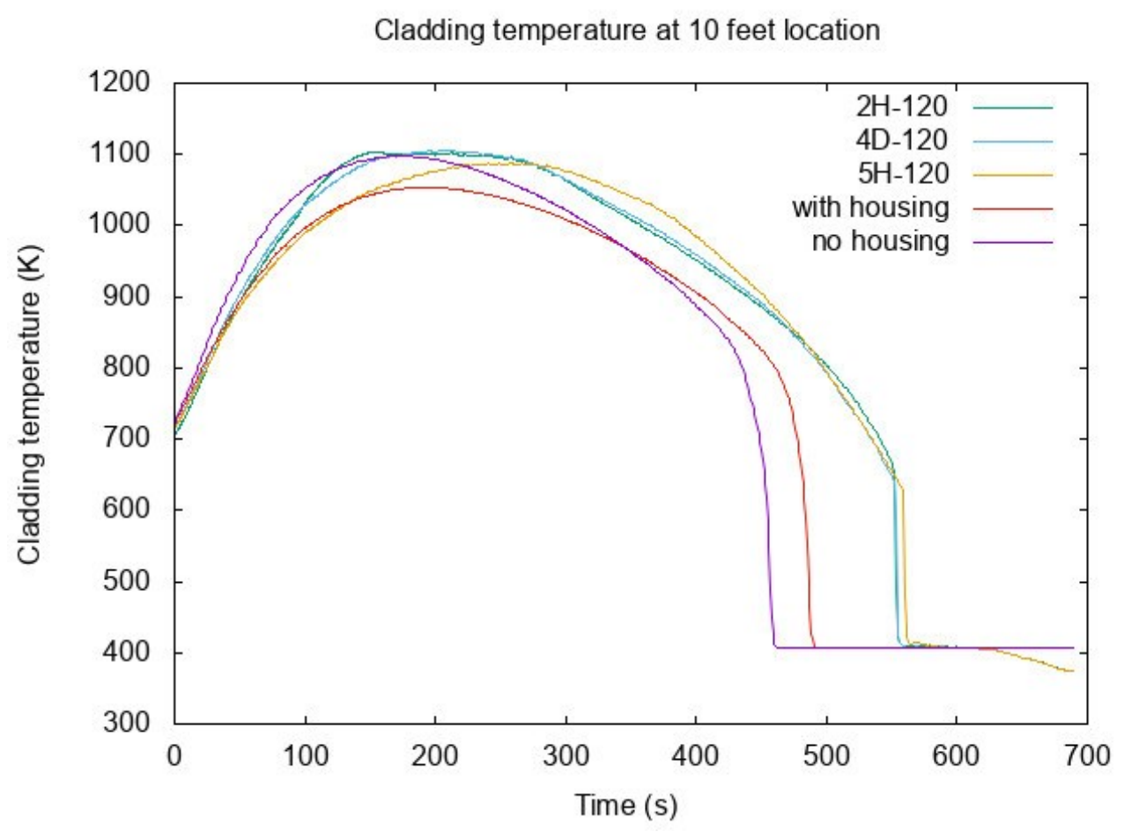

Figure 6. Cladding temperature at 10 feet location of test 31504

Table 5. PCTs and QTs calculated in cases of with and without housing structure modelling.

Test No.	PCT (K)			QT (s)		
	2 ft	6 ft	10 ft	2 ft	6 ft	10 ft
Test 31504						
w/ housing	720.7	1337.9	1053.7	33	222	512
w/o housing	721.2	1357.2	1097.6	42	216	463
Test 31701						
w/ housing	679.5	1132.4	734.2	3	66	99
w/o housing	679.4	1137.8	1103.9	9	70	110

6. Conclusions

Totally 6 kinds of sensitivity study have been performed for Test 31504, Test 31701 and Test 31805 of FLECHT-SEASET experiment. The main results from this sensitivity study were the high importance of nodalization, grids modeling, using developer option 40 and housing heat structure to peak cladding temperatures and quenching time of reflooding process; their aspects must be considered when analysis of reflooding phenomena in FLECHT-SEASET. This sensitivity study is also useful for MARS code user when modeling and choosing input options to analysis of large break loss of coolant accident in nuclear power plant.