Evaluation of Reflood HTC and CRF of RELAP5/MOD3.1/K for the New LOCA M/E Analysis

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1. Introduction

The New LOCA Mass and Energy (M/E) release analysis methodology [1] has been developed by coupling two computer codes, RELAP5/MOD3.1/K for the RCS thermal hydraulic analysis and CONTEMPT4/MOD5 for the containment back pressure analysis.
During the development, review and comparison of regulations for equipment qualification, domestic and international status of relevant techniques, and thermal hydraulic models of the best-estimate codes were necessary to assure its compliance with current regulation. Especially, major modeling parameters which affects most the analysis results should be carefully evaluated from the licensing viewpoint.
In this paper, reflood Heat Transfer Coefficient (HTC) and Carryover Rate Fraction (CRF) among various main parameters are selected, simulated, and compared with the experimental data of the FLECHT (Full Length Emergency Cooling Heat Transfer) facility to assess the applicability of RELAP5/MOD3.1/K to the new LOCA M/E release analysis.

2. FLECHT Experiment and Analysis Methods

2.1 Description of FLECHT Experiment

The objective of FLECHT test [2-4] was to obtain experimental data for use in evaluating the heat transfer capabilities of pressurized water reactor emergency core cooling systems under simulated LOCA conditions. The PWR-FLECHT tests were conducted with 7x7 and 10x10 heater rod bundles having principal dimensions typical of commercial PWR fuel assemblies, as follows:
Heated length - 12 feet
Heated pitch - 0.563 inches, square pitch
Heater diameter - 0.422 inches
Control rod thimble diameter – 0.545 inches
Instrumentation tube diameter – 0.463 inches

2.2 Analysis Methods

Table 1 shows the initial conditions for the four FLECHT tests. These four FLECHT tests are chosen to simulate the reflood heat transfer because these tests covered the wide range of thermal hydraulic initial conditions.
The test section is modeled using 20 uniform cells. Measured fluid conditions are used to define the thermal hydraulic conditions in the upper and lower time dependent volumes, which represent the upper and lower plena, respectively. The measured flow injection velocity is used to define the flow conditions at the time dependent junction that connects the lower plena and the test section. The measured power, which is decreasing during the test period, is used as input for heat structures representing the rods. With axial power distribution, the calculation is started with injection of the water and the decay of heater power.

Table 1. Conditions for FLECHT Test

FLECHT Test No.	Initial Cald Temp (°F)	Flooding Rate (in/sec)	Peak Power Density (kw/ft)	Inlet Coolant Temp (°F)	Bundle Size
0690	1531	0.6	0.69	190	10x10
6948	1615	1.0	1.24	146	7x7
4225	1596	1.9	1.24	153	10x10
3541	1598	5.9	1.24	148	10x10

3. Results and Conclusion

Figures 1 and 2 provide comparisons of the RELAP5/MOD3.1/K predictions of heat transfer against experimental data for the two FLECHT tests listed in Table 1. Figure 1 shows the HTCs of FLECHT test and the RELAP5/MOD3.1/K for Run No. 6948 with an injection velocity of 1.0 in/sec. The HTCs of RELAP5/MOD3.1/K at 2 ft was slightly higher than experimental data. However, at 6 and 12 ft, the HTCs were much higher than experimental data from 0 seconds.
Figure 2 shows the comparison for Run No. 3541 with a high reflooding rate (water injection velocity of 5.9 in/sec). The HTCs of RELAP/MOD3.1/K at 6 ft elevation was also higher than experimental data. It is concluded that the overestimation of HTCs in RELAP5/MOD3.1/K will provide a large heat transfer to the coolant during a reflood phase. Thus the HTCs without additional multiplier in the new LOCA M/E analysis is conservative compared with the experimental data.
Polynomial curve fit for CRF to the RELAP5/MOD3.1/K data are provided in Figure 3. This curve fit demonstrates that the average CRF produced by the RELAP5/MOD3.1/K models provides a conservative estimate of the CRF compared to the FLECHT test data. Therefore, these models meet the recommendation specified in Section 6.2.1.3 of the

Standard Review Plan (SRP)(NUREG-0800) for cold leg breaks during the core reflood phase as:
"Calculations of liquid entrainment; i.e., the carryover rate fraction, which is the mass ratio of liquid exiting the core to the liquid entering the core, should be based on the PWR FLECHT experiments "

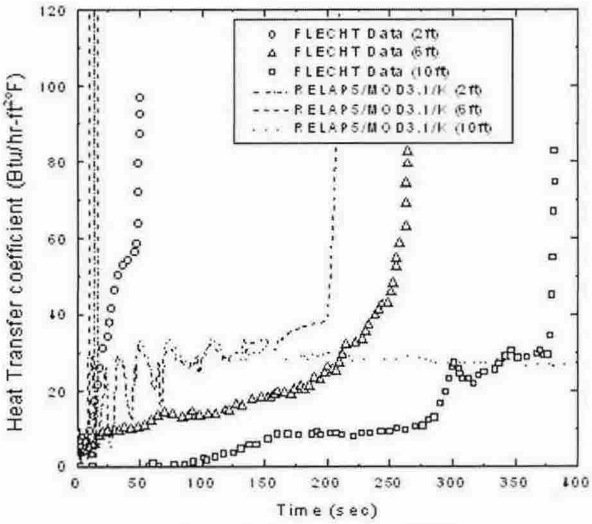

Figure 1. Reflood HTCs for Run No. 6948

The RELAP5/MODE3.1/K produced a significant fluctuation of the predicted CRF whereas the test series did not demonstrate such fluctuations. There are two reasons that may contribute to this behavior:
RELAP5/MOD3.1/K uses a vertical flow regime map to determine the type of flow through a vertical volume (annular mist flow, slug flow, etc.). The flow regime map employed in RELAP5/MOD3.1/K is illustrated in Figure 3.2-1 of Reference 5. As provided in this figure, changes in the vapor void fraction can result in step changes between flow regimes. These step changes can result in a significant variation in the CRF. The initial conditions for the RELAP5/MOD3.1/K FLECHT test model were set equal to the experimental data for the early heat up phase of the events according to the description provided in References 2 through 4. The RELAP5 FLECHT test models should be reexamined to ensure that they achieved a true steady-state operating condition before initiation of the FLECHT test transients.
Compared to the experimental data, RELAP5/MOD3.1/K yields conservative CRF, and therefore, the CRF in the new LOCA M/E analysis methodology can be applicable to the licensing calculation.

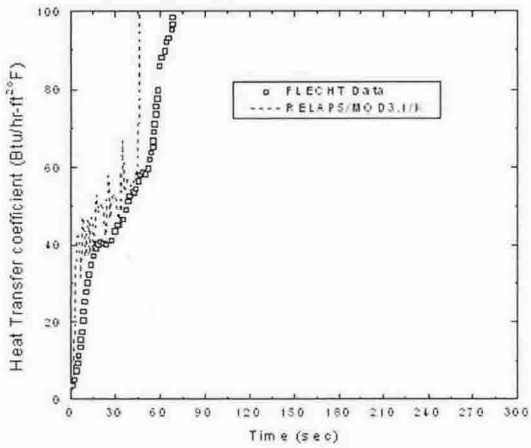

Figure 2. Reflood HTCs for Run No. 3541
(6 ft Elevation)

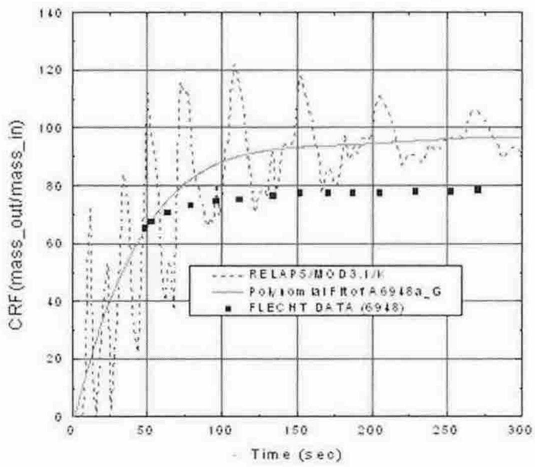

Figure 3. Comparison of CRFs (Run No. 6948)

REFERENCES

[1] C.W. Kim et al., "Development of LOCA M/E Release Analysis Methodology for Equipment Qualification," KNS Conference, October 2004.
[2] WCAP-7931, "PWR FLECHT Final Report Supplement," October 1972.
[3] WCAP-7665, "Full Length Emergency Cooling Heat Transfer (FLECHT) Final Report," April 1971.
[4] WCAP-7435, "PWR Full Length Emergency Cooling Heat Transfer (FLECHT) Group II Test Report, September 1970.
[5] NUREG/CR-5535, "RELAP5/MOD3 Code Manual, Vol. 4"