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Assessments of FLECHT SEASET Unblocked Forced Reflood Tests Using RELAP5/MOD3

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RELAP5/MOD3 코드를 이용한 FLECHT SEASET의 강제 재관수 실험에 대한 평가

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Abstract

FLECHT SEASET unblocked forced reflood tests are assessed using Apollo version of RELAP5/MOD3 5M5. The main purpose of the study is to examine the code predictability under forced reflood conditions having different initial power levels and flooding rates. Among various test matrices, the assessment calculations are performed for the test numbers 31701, 31302, 31203, 31805, 34524, 31021, 34006 and 35807. These have been selected because they have similar initial conditions but different initial peak rod powers or flooding rates. In addition, various sensitivity calculations are performed for test number 31203 on the improved models of RELAP5/MOD3. Those are for the effect of Counter Current Flow Limit (CCFL) option at the outlet junction of the test section, for the effect of grid modelling on the interfacial drag calculations as well as on the heat structure calculations, and for the effect of nodalization and the time step size. The results of sensitivity studies show that the improved models of RELAP5/MOD3 enhance the code predictability. The assessment results show that the RELAP5/MOD3 has a tendency to underpredict the turn around temperature and the turn around time. But RELAP5/MOD3 slightly overpredicts the turn around temperature for high flooding rate. The results also show that the calculated quenching by RELAP5/MOD3 is delayed with the increase of the rod power or the decrease of the flooding rate.

요 약

RELAP5/MOD3 5M5 코드의 Apollo version을 이용하여 FLECHT SEASET 강제 재관수 실험을 평가 하였다. 이 연구의 주 목적은 출력과 관수율의 초기값이 각기 다른 강제 재관수 조건하에서의 코드의 예측능력을 검사하는 것이다. 많은 실험 중에서 8가지 경우에 대해 평가 하였다. 이 8 가지 경우는 출력과 관수율외의 다른 초기 조건들은 유사한 값들을 갖는 것들이다. 또한 RELAP5/MOD3의 개선된 모델(model)들에 대해 여러가지 민감도분석을 하였다. 즉, test section의 outlet junction에서의 Counter Current Flow Limit (CCFL) option의 영향과 heat structure와

interfacial drag의 계산에 미치는 grid modelling의 영향과 nodalization의 영향 및 time step size의 영향등을 분석하였다. 이러한 민감도분석을 통해 코드의 예측능력을 향상시킬 수 있었다. 평가결과로는 RELAP5/MOD3가 국소최대온도 (turn around temperature)와 그때의 시간 (turn around time)을 일반적으로 낮게 예측하나 관수율이 큰경우에는 국소최대온도를 약간 과대평가 하였다. 또한 출력이 증가하고 관수율이 감소 할수록 RELAP5/MOD3가 quenching을 상대적으로 지연시킴을 알 수 있었다.

1. Introduction

In an attempt to describe realistic system thermal–hydraulics, United States Nuclear Regulatory Commission (USNRC) has developed and assessed several best–estimate (BE) advanced thermal–hydraulics transient code such as TRAC–PWR, TRAC–BWR, RELAP5, COBRA and FRAP which use modeling that attempts to realistically describe the physical processes occurring in a nuclear reactor. Among these BE codes, RELAP5/MOD3 5M5, which is an Idaho National Engineering Laboratory (INEL) official release version of RELAP5/MOD3, has been used to assess FLECHT SEASET (Full Length Emergency Core Cooling Heat Transfer Separate Effects Tests and System Effects Tests). FLECHT SEASET tests were conducted in order to improve understandings of the reflood thermal–hydraulics during a postulated loss of coolant accident (LOCA) of Pressurized Water Reactor (PWR). FLECHT SEASET unblocked bundle tests consist of reflood (forced and gravity) and steam cooling tests.

The main purpose of these RELAP5/MOD3 assessments is to examine the code predictability under forced reflood conditions having different initial power levels and/or flooding rates. Before the assessments, sensitivity studies were performed for CCFL option at the outlet junction of the test section, for the grid modelling on the interfacial drag calculation as well as on the heat transfer calculation, for the nodalization of the test section and for the time step size. Through these sensitivity studies, the optimized input modelling was selected to assess FLECHT SEASET. Among forced reflood tests, 8 tests were assessed in order to examine the code predictability under forced reflood conditions. The outputs of the assessment have been analyzed for turn around temperature, turn around time and quenching time. Occurring during the reflood phase, these variables are chosen for code predictability. The assessment results show that the RELAP5/MOD3 has a tendency to underpredict the turn around temperature, even though it slightly overpredicts the turn around temperature for high flooding rate case. The results also show that the calculated quenching by RELAP5/MOD3 is delayed with the increase of the rod power or the decrease of the flooding rate.

Section 2 describes the nodalization and the analysis modellings. The sensitivity studies and those results are described in section 3 and the assessment results are discussed in section 4. Finally, section 5 concludes the results of the studies.

2. Analysis Methods and Models

2.1. Nodalization

Figure 1 shows the nodalization used to simulate the unblocked bundle, forced reflood tests of the FLECHT SEASET. The test section is nodalized as pipe having 20 equi–length subvolumes. Upper plenum and lower plenum are modeled as time dependent volumes. Constant forced flooding rate is modelled by time dependent junction having constant flow. For detailed information on the test facility, see References [1–3].

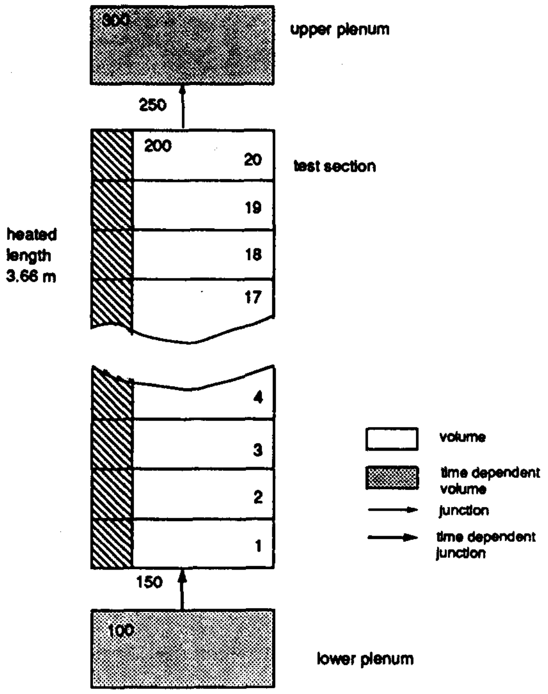


Fig. 1. Nodalization for FLECHT SEASET Simulation

2.2. Analysis Modelling

The CCFL option is not used at the outlet junction of test section. The grid effect on the interfacial drag is considered by subtracting the grid area from the area of a near junction and also by subtracting the grid volume from the relevant hydraulic volume. The grid effect on the heat structure calculation is also modelled. The vertical stratification option is on and the selected maximum time step size is 0.01 second.

2.3. Test Initialization

In order to provide proper initial conditions of thermal-hydraulic environments and radial/axial temperature profile of heat structures, reflood initial conditions of tests are initialized following the test procedure. The heater rods are heated up to constant power from the given initial environmental conditions. The conditions of the time at which the peak cladding temperature is similar to the experimental data is selected as the initial conditions of the assessment calculations. Figure 2 shows the typical comparison of initialized cladding temperature distribution and that of experiment. In this figure, dashed line represents the cladding temperature distribution calculated using the least square method. The solid line and circles

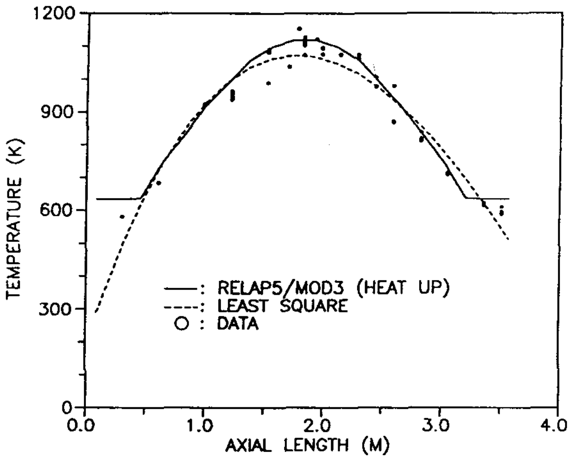


Fig. 2. Initial Cladding Temperature Distribution for Test No. 31203(FLECHT SEASET)

indicate the initialized cladding temperature distribution of RELAP5/MOD3 and experiment, respectively. Then, the transient calculation is restarted from these initialized conditions with the decay power following ANS'71+20% decay curve which is the decay power used in the experiment.

3. Sensitivity Study

Sensitivity calculations are performed to support various modelling features involved in the assessment calculations. These are for the RELAP5/MOD3 options on the CCFL at the outlet junction of the test section, on the bundle interfacial drag calculations and for the grid modelling on the interfacial drag calculation and on the heat structure calculations. Besides them, also

Table 1. Sensitivity Study for Test 31203

	CCFL option	Grid model ling on the		Nodaliz-ation	Maximum time step (sec.)	Inter-facial model
		inter.drag	heat stru.			
Run 1	off	off	off	20	0.01	B
Run 2	on	off	off	20	0.01	B
Run 3	off	on	off	20	0.01	B
Run 4	off	off	on	20	0.01	B
Run 5	off	on	on	20	0.01	B
Run 6	off	on	on	20	0.01	P
Run 7	off	on	on	20	0.1	B
Run 8	off	on	on	20	0.005	B
Run 9	off	on	on	10	0.01	B
Run 10	off	on	on	40	0.01	B

sensitivity studies are performed for the maximum time step size and for the nodalization of the test section. Test number 31203 is selected as the reference test for the sensitivity studies and Table 1 lists the classification of the sensitivity studies. In this table, 'B' and 'P' stand for rod bundle interfacial friction model and pipe interfacial friction model, respectively.

Effect of code options are tested by turning on or off their flags. Spacer grid effect on interfacial drag calculations is tested by subtracting relevant junction area and volume occupied by the grid. Spacer grid effect on the heat structure calculations is examined by providing the grid spacer length forward and reverse from the nearest grid locations.

Noding sensitivity studies are performed to optimize number of equi-distance axial nodes of test section. Also, the sensitivity on the maximum time step size is tested as shown in Table 1 (Run 7 and 8).

The calculation statistics are summarized in Table 2. In Table 2, the numbers in the parenthesis in the advancement column represent requested advancement numbers by maximum time step size. Table 3 shows the calculated results of the sensitivity studies. Heights in the tables represent the locations where the cladding tempera-

Table 2. The CPU Time and Attempted Advancement for Sensitivity Study

	Real Time (se.)	CPU Time (sec.)	Attempted Advancement
Run 1	419	10023.8	48048 (42710)
Run 2	419	9952.8	47971 (42710)
Run 3	419	10116.4	48312 (42710)
Run 4	419	9241.6	46737 (42710)
Run 5	419	9376.7	46955 (42710)
Run 6	419	9874.6	47909 (42701)
Run 7	419	5208.5	26852 (5000)
Run 8	419	16937.0	85252 (84410)
Run 9	419	4915.5	43548 (42530)
Run 10	419	23143.8	64478 (42710)

Table 3. Relative Errors for Sensitivity Study

		Height (cm)									
		99.1	121.9	182.9	198.1	228.6	243.8	281.9	304.8	avg. err.	std. dev.
Run 1	TT	-.0523	0.0271	-.0537	-.0790	-.0456	-.0706	-.0379	-.0387	-.0439	0.0301
	AT	-.5433	-.1197	-.3307	-.2711	-.2486	-.3485	-.1208	-.4270	-.3012	0.2316
	QT	-.2407	-.29.16	-.2640	-.2846	-.3215	-.2991	-.3546	-.3800	-.3045	0.0430
Run 2	TT	-.0492	0.0320	-.496	-.0763	-.0483	-.0733	-.0392	-.0374	-.0427	0.0313
	AT	0.0288	-.0845	-.4193	-.4315	-.2370	-.3465	-.1426	-.4350	-.25.84	0.0724
	QT	-.2144	-.2907	-.2640	-.2858	-.2625	-.2584	-.3141	-.3444	-.2793	0.0367
Run 3	TT	-.0617	0.0250	-.0550	-.8010	-.0496	-.0745	-.0434	-.0482	-.0486	0.0304
	AT	-.5865	-.1549	-.3012	-.2274	-.3757	-.3168	-.1248	-.4050	-.3116	0.0617
	QT	-.2019	-.2402	-.2599	-.2253	-.3186	-.2962	-.3182	-.3663	-.2783	0.0521
Run 4	TT	-.0447	-.0254	-.0501	-.0738	-.0414	-.0661	-.0332	-.0311	-.0394	0.0282
	AT	-.4519	-.1901	-.3944	-.3542	-.2254	-.3366	-.1109	-.3800	-.3055	0.0513
	QT	-.1992	-.2112	-.1797	-.0976	-.1209	-.1003	-.1566	-.2045	-.1588	0.0440
Run 5	TT	-.0447	0.0254	-.0528	-.0787	-.0498	-.0769	-.0392	-.0443	-.0476	0.0258
	AT	-.4519	-.0669	-.4270	-.4461	-.3526	-.2891	-.0792	-.4930	-.3317	0.0906
	QT	-.1992	-.2037	-.1270	-.0486	-.1976	-.0650	-.2663	-.1885	-.1504	0.0704
Run 6	TT	-.0566	0.0105	-.0584	-.0843	-.0552	-.0781	-.0415	-.0523	-.0520	0.0270
	AT	-.4519	-.0845	-.4348	-.4461	-.3757	-.3416	-.1881	-.5545	-.3597	0.0995
	QT	-.1867	-.2860	-.2432	-.1885	-.3215	-.2633	-.3920	-.3708	-.2815	0.0718
Run 7	TT	-.0413	0.0144	-.0508	-.0756	-.0464	-.0729	-.0370	-.0434	-.0441	0.0259
	AT	-.4327	-.2148	-.3944	-.4271	-.3064	-.2663	0.0733	-.5120	-.3284	0.0914
	QT	-.0816	-.1907	-.1617	-.1134	-.1917	-.1361	-.2925	-.2425	-.1763	0.643
Run 8	TT	-.0384	0.9328	-.0444	-.0703	-.0368	-.0659	-.0370	-.0411	-.0376	0.0293
	AT	0.0577	-.1725	-.3866	-.4169	-.3179	-.4079	-.0406	-.4570	-.2677	0.0872
	QT	-.0927	-.1486	-.1122	-.0316	-.0767	-.0592	-.2070	-.1732	-.1126	0.0559
Run 9	TT	0.0014	0.0673	-.0342	-.0567	-.0546	-.0804	-.0539	-.0770	-.0360	0.0459
	AT	0.1538	-.1549	-.2314	-.2726	-.4220	-.4327	0.0347	-.4590	-.2317	0.4365
	QT	0.2766	0.2589	0.2041	0.2834	-.7528	-.8301	-.1391	-.1456	-.1056	0.4290
Run 10	TT	-.0383	0.0149	-.0466	0.7001	-.3011	-.0650	-.0232	-.0133	-.0341	0.0229
	AT	0.0096	-.2254	-.4876	-.3361	-.3179	-.3950	-.1455	-.4350	-.2917	0.0908
	QT	-.3001	-.3346	-.2270	-.1249	-.1445	-.2078	-.2177	-.3344	-.2364	0.0754

tures were measured. TT means turn around temperature, which represents peak cladding temperature (PCT) of the location, AT stands for turn around time and QT for quenching time. The relative error is calculated by Equation (1). Since most of calculated locations of cladding temperatures are different from those of measured, the calculated values are weighted to measurement locations using the linear interpolation. And, among 12 measurement locations, 4 locations at the bottom and top are excluded in the generation of tables, since PCT is not considered to occur at these locations and their initial temperatures are higher than measured values.

Relative error

$$=\frac{\text{calculated value}-\text{experimental value}}{\text{experimental value}} \quad (1)$$

3.1. Sensitivity on CCFL Option

As given in Table 2 and 3, the CCFL option has little impacts on the calculated cladding temperatures and calculation statistics. And, since the CCFL model in the form of Wallis is quite geometry-dependent, the CCFL option is currently not recommended for the assessment calculations of FLECHT SEASET whose geometry effect on CCFL is unknown [11]. However, more studies will be necessary to model CCFL for the improvement of code predictability.

3.2. Sensitivity on Junction Interfacial Drag Model

The reflood thermal-hydraulics, especially the void profile through test section, is mostly influenced by junction interfacial drag calculation. RELAP5/MOD3 has two models for the calculation of interfacial drag, one is for pipe and the other is for rod bundle geometry [11, 13]. Thus, their effects on reflood thermal-hydraulics were tested as sensitivity studies. Since the experimental value of local interfacial drag can not be measured directly, the comparison of the interfacial drag options is carried out by comparing the amounts of entrained water. Here, the entrained water means the total water drainage at the outlet junction of the test section. Figure 3 shows comparison of these models with the experiment. Here, 'PIPE DRAG' and 'BUND. DRAG' mean. that the pipe interfacial friction model is applied and the rod bundle interfacial friction model is applied, respectively. As can be seen in Figure 3, both models produce similar amount of total entrained liquid, while RELAP5/MOD3 still overpredicts its amount. From this investigation, it can be said that

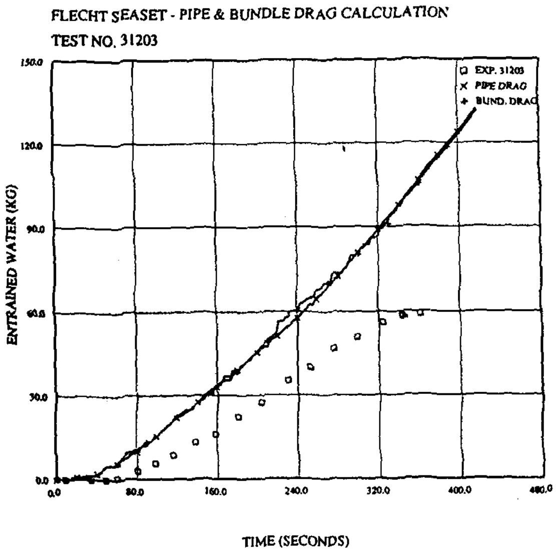


Fig. 3. Comparison of Water Entrainment

the effects of interfacial drag model selection is negligible. Table 3 also explains that the turn around temperature and turn around time are hardly affected, even though quenching time is slightly delayed when using rod bundle interfacial drag model. In order to describe the actual test facility, the rod bundle model is adopted for the further calculations.

3.3. Sensitivity on Grid Modelling

As given in Table 3, the spacer grid modelling for the interfacial drag calculation has little impact on the calculated results. However, the spacer grid modelling for heat structure calculation has positive effects on the quenching time so the quenching time tends to be in agreement with the experiment comparatively. Moreover, if enhances the calculation statistics as given in Table 2, that is, the number of the attempted advancement are decreased and the calculation time per unit time step advancement is reduced. Thus, in the sense that the spacer grid was actually equipped in the test facility, it is recommended to model spacer grid for interfacial drag calculations as well as for heat transfer calculations. The calculated results with both grid modelling are provided as Run 5 in Table 3.

3.4. Maximum Time Step Size Sensitivity

To optimize maximum time step size, sensitivity calculations are performed for the maximum time step size of 0.1 second, 0.01 second and 0.005 second. As shown in Table 3, the code predictability, especially for quenching time, slightly improves with the reduction of maximum time step size. However, the total CPU time increases with the reduction of it as given in calculation statistics in Table 2. For the case of 0.1 second, the material courant limit leads more frequent time step control such that the total CPU time is quite larger than expected. The frequent time step control may lead to unexpected deviation of calculated results due to the RELAP5/MOD3 iteration numerical scheme. Thus, considering the accuracy of calculated results and CPU statistics, it is concluded to use 0.01 second for the reflood assessments, which is also recommended for use in RELAP5 user's guideline.

3.5. Nodalization Sensitivity

The FLECHT SEASET heater rods have 15 axial power steps to describe chopped cosine shape of core power distribution, where the power of both ends of heater rods are lumped into single low power. In order to describe actual power distribution of heater rods, the basic nodalization scheme is selected to be 20 equi–distance axial subdivision of the test section. Then, the nodalization sensitivity studies are carried out for equi–distance axial noding of 10 and 40. The calculated results are summarized in Table 3. As shown in Table 3, the noding by 10 seems to result in better predictability, but the transient behavior of cladding temperature are non–physical

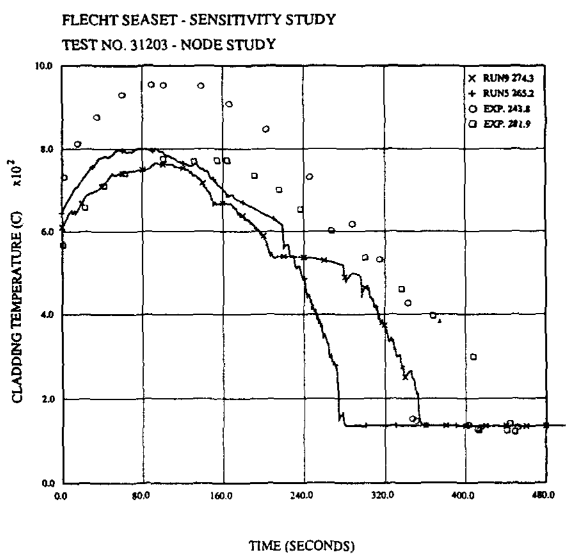


Fig. 4. Comparison of Cladding Temperatures

as shown in Figure 4. And, even, the better predictability seems to be due to a large compensation of cladding temperature caused by lumping two power zones into one zone. For the noding by 40, there is not much benefit of predictability improvements compared to the increased calculation time as given in Table 2. Thus, it is concluded that the optimum nodalization of the further assessment calculations is to be the 20 equi–distance noding of test section.

4. Assessment Results and Discussion

Among the forced reflood tests given in Figure 5, 8 tests are selected for the assessment calculations. Figure 5 shows the test matrix of the forced reflood tests rearranged on the rod peak powers and flooding rates. These selected tests are circled in Figure 5 and listed in Table 4. As can be seen in this table, the selected tests have different flooding rate and/or rod peak power under similar initial cladding temperature, pressure and coolant temperature. The reason for the selection is to investigate the effect of flooding rate and rod power, which are thought to govern reflood phe-

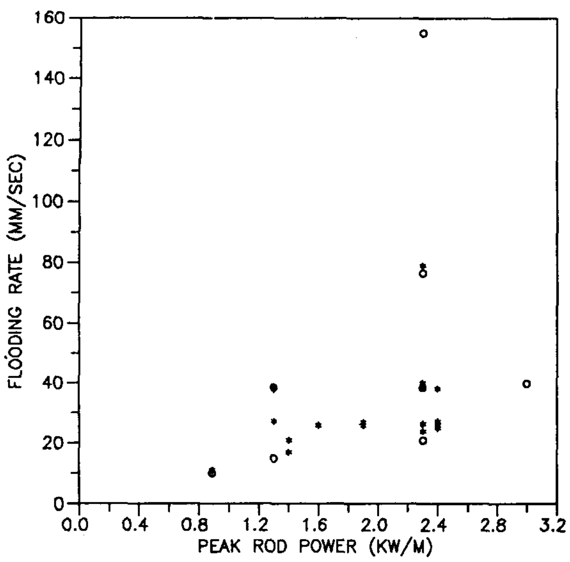


Fig. 5. FLECHT SEASET Test Matrix for Constant Flooding Rate

nomena, by remaining the effect of the other variables.

Table 5 shows the relative errors of the turn around temperature, the turn around time and the quenching time for the assessment calculations.

4.1. Turn Around Temperature

Figure 6 shows the comparisons of the turn around temperatures of the RELAP5/MOD3 with the experimental results. The calculated results of their uncertainties are also given in the figure. Here, the standard deviation represents for relative error. In the case of the test 31701, since the flooding rate is very high, the cladding is not heated up but cooled down as soon as coolant is injected to the test section. Therefore, this test is excluded from the analysis of the turn around temperature and the turn around time.

As shown in Figure 6, the RELAP5/MOD3 generally underpredicts the turn around temperature and it seems that there is nearly no effect of the rod power on it.

Figure 6 and 7 show the effect of the flooding rate on the turn around temperature. Unlike the case of the rod power, the effect of the flooding rate can be seen. And as shown in the figures, the RELAP5/MOD3 has tendency to underpredict the turn around temperature at low and medium flooding rate and overpredict it at high flooding rate. This trend becomes more evident at higher elevation of heater rods as shown in Figure 7.

This tendency at high elevation is probably due to the presence of the 'grid in the test facility, whose effects on thermal-hydraulics are not accurately modelled in RELAP5/MOD3. Physically, when the flow regime is at dispersed two-ph-

Table 4. Assessment Matrix

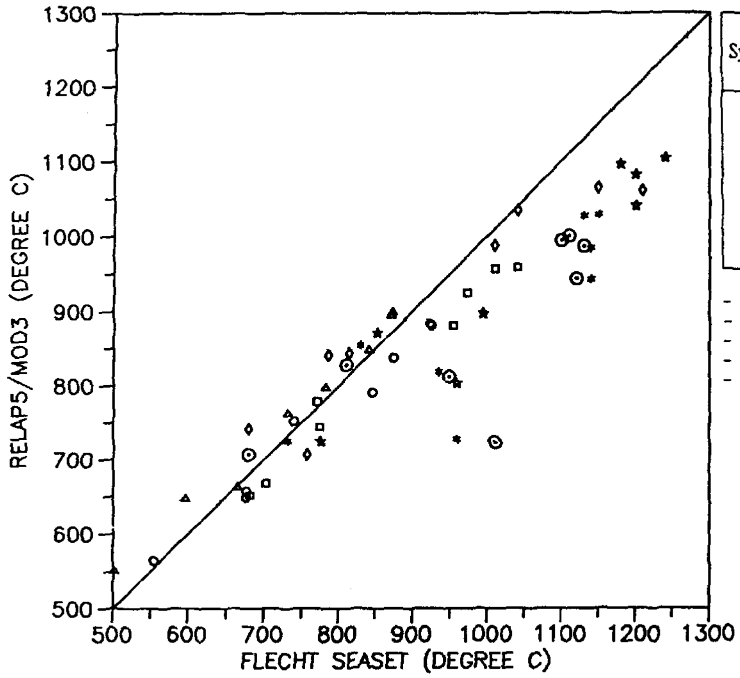
Exp. no.	Peak power (kw/m)	Flooding rate (m/sec)	Coolant temp. (℃)	Press. (MPa)	Rod initial Tclad at 1.83m(℃)
34524	3.0	0.0399	52	0.28	878
31701	2.3	0.1550	53	0.28	872
31302	2.3	0.0765	52	0.28	869
31203	2.3	0.0384	52	0.28	872
31805	2.3	0.0210	51	0.28	871
31021	1.3	0.0386	52	0.28	879
34006	1.3	0.0150	51	0.27	882
35807	0.89	0.0100	50	0.28	886

Table 5. Relative Errors for Assessment Test

		Height (cm)									
		99.1	121.9	182.9	198.1	228.6	243.8	281.9	304.8	avg. err.	std. dev.
Test 31701	TT	-.039	0.038	-.025	0.003	-.027	-.013	-.002	0.039	-.003	0.027
	AT	-.787	-.756	-.508	-.333	-.388	-.434	-.689	0.000	-.315	0.445
	QT	-.060	-.230	-.094	-.087	-.244	-.323	-.555	-.458	-.256	0.169
Test 31302	TT	-.003	0.045	0.030	0.028	0.010	0.021	0.086	-.102	0.040	0.034
	AT	-.677	-.091	0.667	-.227	1.785	0.214	3.609	0.056	0.667	0.236
	QT	-.246	-.302	-.294	-.283	-.375	-.411	-.514	-.497	-.365	0.095
Test 31203	TT	-.049	0.011	-.053	-.079	-.050	-.077	-.039	-.044	-.048	0.026
	AT	-.500	-.067	-.427	-.446	-.353	-.289	-.079	-.493	-.332	0.091
	QT	-.109	-.204	-.127	-.049	-.198	-.065	-.266	-.186	-.150	0.070
Test 31805	TT	-.065	0.023	-.071	-.110	-.098	-.133	-.099	-.161	-.089	0.052
	AT	-.033	-.183	-.467	-.520	-.423	-.386	-.220	-.390	-.328	0.155
	QT	-.010	0.240	0.256	0.353	0.261	0.219	0.110	0.035	0.183	0.117
Test 34524	TT	-.066	0.036	-.124	-.075	-.006	-.022	-.070	-.090	-.012	0.070
	AT	-.253	0.036	-.475	-.554	-.394	-.182	0.129	-.271	-.246	0.222
	QT	-.064	-.018	0.715	1.469	1.056	0.840	0.596	0.696	0.661	0.479
Test 31021	TT	-.029	0.016	-.043	-.047	-.042	-.065	-.042	0.017	-.029	0.028
	AT	-.675	-.194	-.582	-.491	-.293	-.511	-.314	-.003	-.383	0.150
	QT	-.132	-.260	-.275	-.279	-.355	-.307	-.354	-.327	-.286	0.067
Test 31006	TT	-.009	0.029	-.106	-.091	-.138	-.173	-.125	-.242	-.107	0.081
	AT	0.141	0.012	-.489	-.596	-.320	-.406	-.284	-.411	-.294	0.082
	QT	0.135	0.066	0.133	0.093	0.065	-.051	-.035	-.031	0.047	0.071
Test 31006	TT	0.041	0.022	-.097	-.100	-.127	-.158	-.145	-.284	-.106	0.097
	AT	0.303	-.025	-.312	-.306	-.270	-.407	-.245	-.226	-.186	0.211
	QT	0.119	0.078	0.001	-.058	-.051	-.109	-.138	-.126	-.035	0.099

ase droplet flow, the grids will promote additional heat transfer effects because of grid rewetting and shattering of the entrained droplets [5]. These mentioned effects are more dominant with high flooding rates. Moreover, the flow regime at the vicinity of quench front is at inverted annular mode for high flooding rates. In this case, liquid droplets are easily detached from the front of a continuous liquid column. Therefore, the higher the flooding rate is, the more dominant the effects of the grids are.

The effect raised by the lack of accurate thermal-hydraulic model for grid in RELAP5/MOD3 can be explained by Figure 8 and 9. In the case of 31805 where the flooding rate is very low and the grid effects are not dominant, the calculated steam temperature is similar with or lower than that of the experiment. However in the case of 31302 where there is a dominant effect of the grids in the experiment, the steam temperature of the calculation is considerably higher than that of the experiment. Thus,it can be concluded that the calculated turn around temperature becomes overestimated at higher flooding rates due to the lack of grid models.



Symbol	Exp. no.	Peak power (kw/m)	Flooding rate (m/sec)
◊	34524	3.0	0.0399
⊕	31701	2.3	0.1550
△	31302	2.3	0.0765
□	31203	2.3	0.0384
☆	31805	2.3	0.0210
○	31021	1.3	0.0386
*	34006	1.3	0.0150
⊙	35807	0.89	0.0100

- number of data : 56
- average of relative error : -0.0502
- standard deviation : 0.0791
- maximum error : 0.1017
- minimum error : -0.2842

Fig. 6. Comparison of Turn Around Temperature

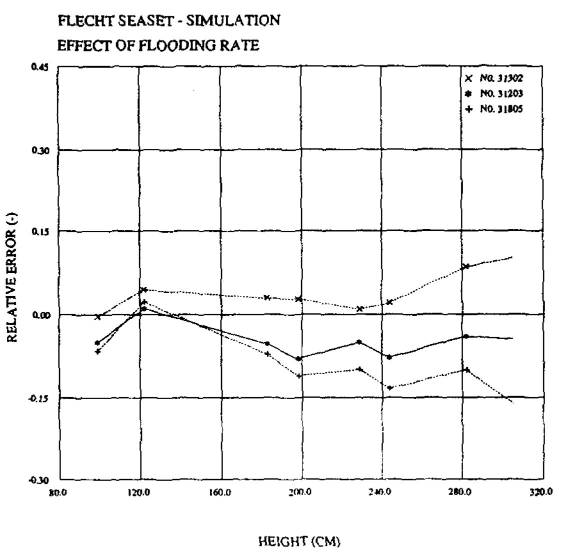


Fig. 7. Effect of Rod Power on Turn Around Temprature

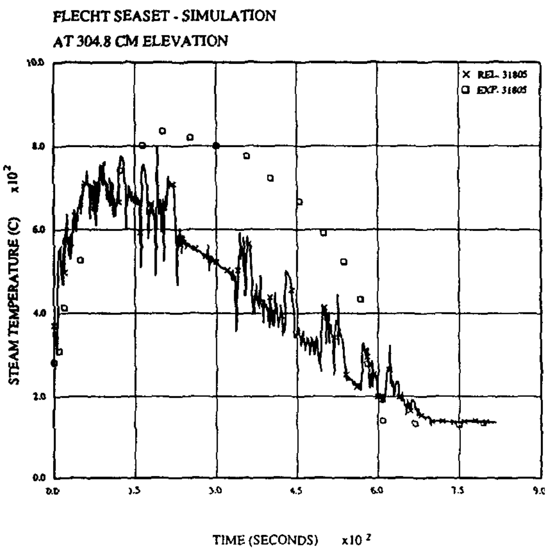


Fig. 8. Comparison of Steam Temp. for Low Flooding Rate

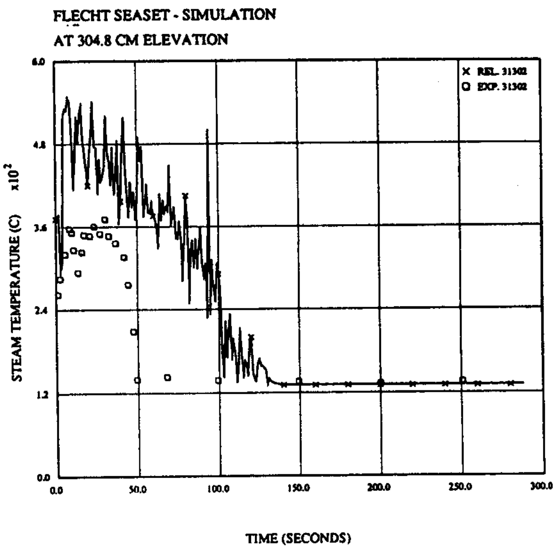
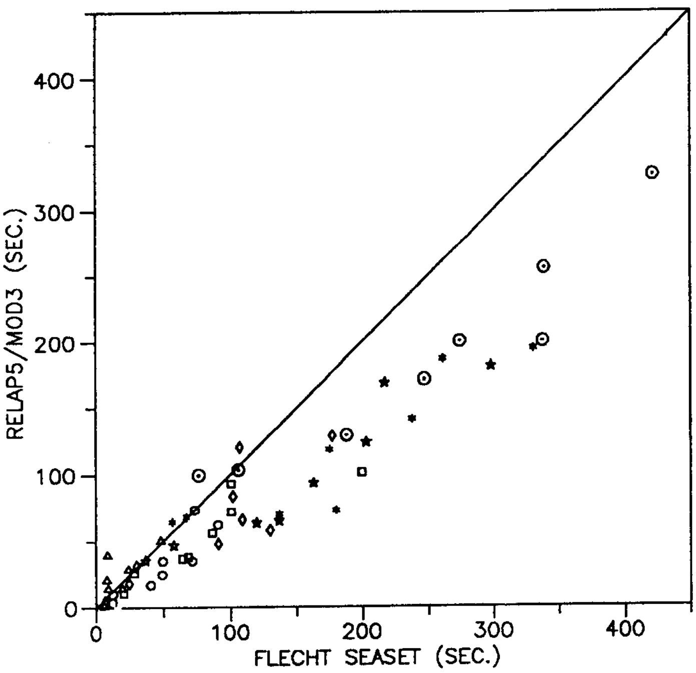


Fig. 9. Comparison of Setam Temp. for High Flooding Rate

4.2. Turn Around Time

Figure 10 shows the comparisons of the turn around times of the RELAP5/MOD3 and the FLECHT SEASET. The calculated results of their uncertainties are also given in the figure. The RELAP5/MOD3 predicts the turn around time considerably faster than measured as shown in the figure. The assessment results show that the turn around times are not influenced by both rod power and flooding rate.

The turn around time occurs at the heat transfer mode of film boiling, where the total heat transferred to fluid is determined by heat transfer to liquid and vapor including radiation. As can be seen in Figure 11, the timing of the turn around temperature corresponds to the decrease of void fraction. Thus, it can be said that the turn around time is determined by increased heat transfer to liquid



Symbol	Exp. no.	Peak power (kw/m)	Flooding rate (m/sec)
◊	34524	3.0	0.0399
⊕	31701	2.3	0.1550
▲	31302	2.3	0.0765
□	31203	2.3	0.0384
☆	31805	2.3	0.0210
○	31021	1.3	0.0386
*	34006	1.3	0.0150
⊙	35807	0.89	0.0100

- number of data : 56
- average of relative error : -0.1573
- standard deviation : 0.6288
- maximum error : 3.6092
- minimum error : -0.6774

Fig. 10. Comparison of Turn Around Times

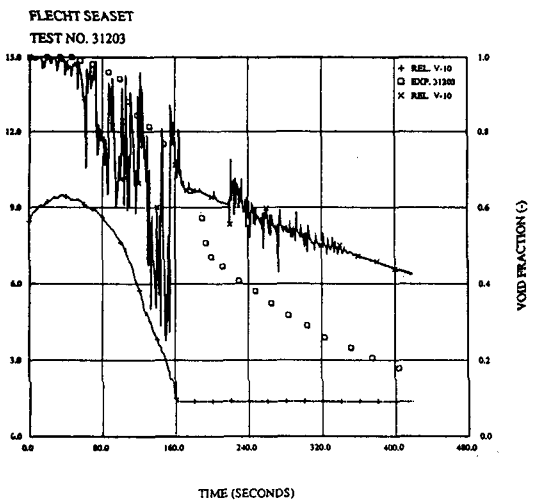


Fig. 11. Comparison of Void Fraction & Cladding Temp.

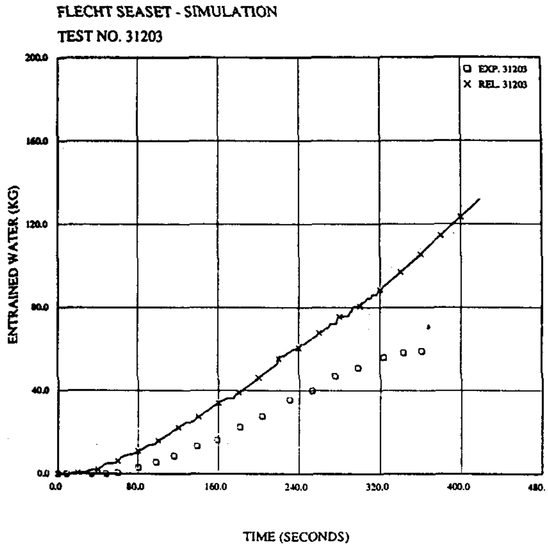
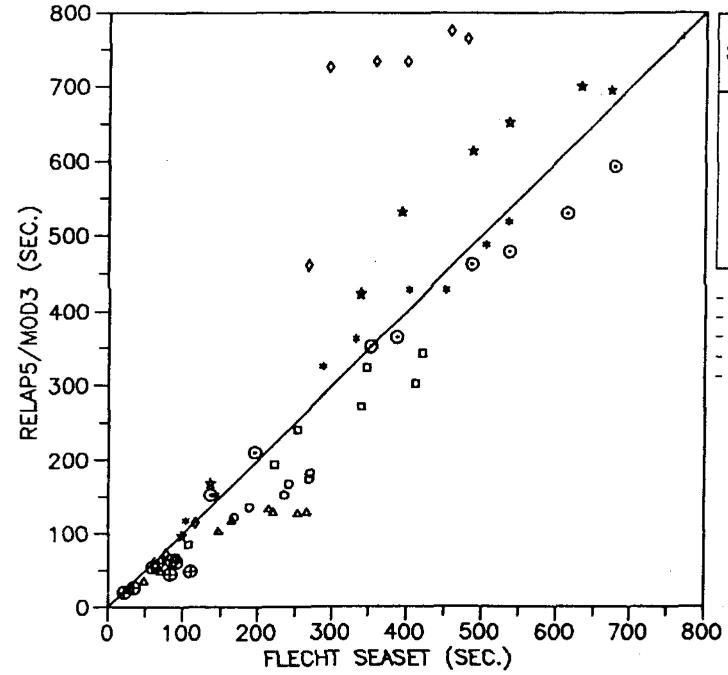


Fig. 12. Commparison of Water Entrainment

phase influenced by the void fraction of transients. This underestimation of void fraction seems to be due to the overestimation of liquid entrainment. Figure 12 represents the total amount of liquid flow at the outlet of test section, and they certify that RELAP5/MOD3 overpredicts the liquid entrainment. Thus, further study on the RELAP5/MOD3 interfacial drag modelling is required.



Symbol	Exp. no.	Peak power (kw/m)	Flooding rate (m/sec)
◇	34524	3.0	0.0399
⊕	31701	2.3	0.1550
△	31302	2.3	0.0765
□	31203	2.3	0.0384
★	31805	2.3	0.0210
○	31021	1.3	0.0386
*	34006	1.3	0.0150
⊙	35807	0.89	0.0100

- number of data : 64
- average of relative error : -0.0253
- standard deviation : 0.3667
- maximum error : 1.4694
- minimum error : -0.5545

Fig. 13. Comparison of Quenching Tims

4.3. Quenching Time

Figure 13 shows the omparison of the quenching times of the RELAP5/MOD3 and the experiment. The calculated results of their uncertainties for quenching are also given in the figure.

As shown in Figure 13 and Table 5, the quenching is delayed as the rod power increases and as the flooding rate decreases.

4.4. Steam Cooling Heat Transfer of RELAP5/MOD3

As shown in Figure 6 and 10 and in Table 5, RELAP5/MOD3 predicts turn around temperature relatively better than the turn around time, which is normally underpredicted by the code. Since the turn around temperature is governed by the turn around time and heat transfer coefficients until the cladding temperature turn-around occurs, the above results imply that the total heat transferred to fluid is underpredicted in RELAP5/MOD3.

The previous analysis [4] on the RELAP5/MOD3 steam cooling heat transfer shows that the RELAP5/MOD3 has tendency to underpredict the stem cooling heat transfer coefficients for relatively low Reynolds number steam flow, which is shown in Figure 14. As shown in this figure, RELAP5/MOD3 calculates six value groups of the heat transfer coefficient. This trend is caused by following reason. RELAP5/MOD3 predicts the coefficient using Dittus-Boelter correlation. And this correlation depends on the thermal properties of vapor. But the experiment was conducted for small changes of vapor temperature and the thermal properties of vapor are nearly constant. And mass flux and equivalent diameter of the experiment were not changed. Therefore, the calculated heat transfer coefficients tend to be constant. For more informations, consult Reference [4].

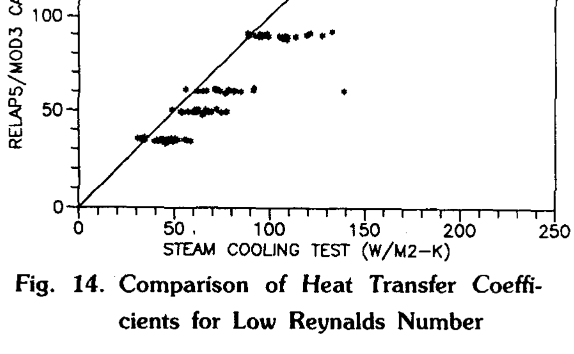


Fig. 14. Comparison of Heat Transfer Coefficients for Low Reynalds Number

5. Conclusions

From the above ten sensitivity studies and the eight assessment calculations, following conclusions are obtained.

For sensitivity studies

- CCFL model in RELAP5/MOD3 has little effect on calculated results.
- The grid modelling on the interfacial drag has nearly no effect on the RELAP5/MOD3 calculation.
- The grid modelling on the heat structure calculation has relatively dominant effect on the quenching time of RELAP5/MOD3.
- The uses of bundle and pipe interfacial drag models result in similar reflood thermal-hydraulics.
- Considering the accuracy of calculated results and CPU statistics, 0.01 maximum time step size and 20 noding of test section were selected for the assessment.

For assessment calculations

- The assessment results show that the turn around temperatures are hardly affected by the variation of rod power, even though it is underpredicted.
- RELAP5/MOD3 has a tendency to underpredict the turn around temperature at low and medium flooding rate and to overpredict it at high flooding rate. The turn around temperature dependency of RELAP5/MOD3 on flooding rate can be explained by the effect of grid which exists in actual facility.
- Turn around times are underpredicted. This underprediction is due to the underestimated void fraction influenced by the overestimation of liquid entrainment. Thus, further studies on the interfacial drag model is required.
- The calculated quenching is delayed as the rod power increases and as the flooding rate decreases.
- REALP5/MOD3 has tendency to underpredict the film boiling heat transfer coefficients, at least until the turn around time.

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