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Assessment of RELAP5MOD2 Cycle 36.04 using LOFT Intermediate Break Experiment L5–1

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LOFT 중형 냉각재 상실 사고 모사 실험 자료 L5-1을 이용한 RELAP5/MOD2 Cycle 36.04 코드 평가

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Abstract

The LOFT intermediate break experiment L5–1, which simulates 12 inch diameter ECC line break in a typical PWR, has been analyzed using the reactor thermal/hydraulic analysis code RELAP5/MOD2, Cycle 36.04. The base calculation, which modeled the core with single flow channel and two heat structures without using the options of reflood and gap conductance model, has been successfully completed and compared with experimental data. Sensitivity studies were carried out to investigate the effects of nodalization at reactor vessel and core modeling on major thermal hydraulic parameters, especially on peak cladding temperature(PCT). These sensitivity items are : single flow channel and single heat structure (Case A), two flow channel and two heat structures (Case B), reflood option added (Case C) and both reflood and gap conductance options added (Case D). The code, RELAP5/MOD2 Cycle 36.04 with the base modeling, predicted the key parameters of LOFT IBLOCA Test L5–1 better than Cases A,B,C and D. Thus, it is concluded that the single flow channel modeling for core is better than the two flow channel modeling and two heat structure is also better than single heat structure modeling to predict PCT at the central fuel rods. It is, therefore, recommended to use the reflood option and not to use gap conductance option for this L5–1 type IBLOCA.

요 약

전형적 PWR 비상노심냉각계통에서의 12 inch 파단사고에 대응하는 LOFT 중형냉각재 상실사고 모사 실험 자료 L5-1을 이용하여 RELAP5/MOD2 Cycle 36.04 전산코드의 평가가 수행되었다. 평가 근거는 기준 코드와 nodalization에 의한 계산 결과가 L5-1 실험 결과와 잘 일치 하는지, 추가적인 민감도 분석 연구로는 이중 노심 유로 및 열적 모델을 고려하고 model 민감도 분석으로는 reflood, gap conductance option 사용 여부에 따른 피복재 온도에 미치는 영향을 관찰하였다. 기준 계산 결과 기준 모델이 L5-1 현상을 대체로 잘 모사하였으나, 피복재가 천천히 가열되고

주변 부위의 피복재 온도가 과대하게 예견되었다. 민감도 분석 결과 단일 열적 모델이 피복재 가열 시작을 10초 개선 하였고, 이중 유로 모델이 주변 온도를 20K 개선하였으나 최대 피복재 온도는 기준 계산시 보다 정확치 못하였으므로, 기준 모델인 단일 유로, 이중 열적 구조 그리고 reflood option은 사용하고 gap conductance option은 사용치 않는 것이 코드의 중형 냉각재 상실 사고 해석시 피복재 온도 관찰의 관점에서 바람직하다.

1. Introduction

The International Code Assessment and Applications Program (ICAP) has been conducted by fourteen nations and multinational organizations under the auspices of the USNRC [1] [2]. The USNRC selected two Best Estimate (BE) codes: RELAP5/MOD2 [3] [4] and TRAC/PF1/MOD1. The goal of the program is to assess the prediction capabilities and models [5] of the current BE thermal hydraulic(T/H) codes utilizing the available facility test and plant data in the world. Korean contributions to ICAP include the assessments of RELAP5/MOD2 using ten experiments and five acutal plant data. Six of the assessments are performed with LOFT Integral Effect Test (IET) data [6] and two with semiscale IET data. Two Separate Effect Test (SET) data for critical flow and condensation are used to assess the code RELAP5/MOD2.

Key thermal and hydraulic phenomena such as blowdown, refill and reflood regarding LBLOCA and SBLOCA separatly are well identified over the past years. Now, it is necessary to investigate the key phenomena of intermediate break LOCA (IBLOCA). The LOFT IBLOCA experiment L5-1 [8] simulated 12 inch diameter ECC line break (14% break of 32 inch main piping) in a typical PWR by utilizing a 0.047m diameter orifice. The RELAP5/MOD2/cycle 36.04 [3] was implemented in 1986 on a CDC 170-875 computer of KAERI. The code was corrected for the indexing errors in subroutine RACCUM, IHTCMP and IRFLHT. There are no changes in physical models and hence the corrected version can also be considered as RELAP5/MOD2 Cycle 36.04. These corrections were based on the update work of KWU and STUDSVIK [11]. Chen and Modro used RELAP5/MOD1 Cycle 13 for pretest [7] and posttest [12] calculations for LOFT L5-1. E.J. Lee and present authors [10] assessed RELAP5/MOD2 Cycle 36.05 by using LOFT SBLOCA Test data L3-7.

To summarize the objectives, this report aims to provide the applicability and optimum modeling of RELAP5/MOD2 Cycle 36.04 for IBLOCA Test L5-1. Since ICAP assessment requires sensitivity studies for nodalization and models, the effect of two nodalization and two model option sensitivities on PCT will be quantified under LOFT L5-1 configuration and experiment sequence. Thus, the results from this IBLOCA assessment will be helpful to model a similiar transient of typical PWR.

2. LOFT Facility and test

2.1 LOFT Facility

The LOFT Integral Effect Test (IET) facility [50 MWt] was designed to simulate the major components and system responses of a commercial four-loop PWR [1]. The LOFT facility consists of (1) a reactor vessel with a nuclear core(4 wt% U-235), (2) an intact loop (a steam generator and two primary pumps parallel), (3) a broken loop (simulated pump and steam generator and two quick opening valves), (4) the blowdown suppression system and (5) the emergency core coolant (ECC) system (two LPSI, two HPSI pumps and two accumulators). To relate LOFT into a PWR, the test facility is designed as follows: (1) the same linear heat generation rate of the large reactor is used, (2) LOFT powers are scaled according to component volumes (1 : 60), (3) flow areas are scaled to provide the identical flow to large reactor values, (4) pipe break areas are set in the ratio of core volume and (5) pressure, temperature and mass flux are identical to large reactor values.

2.2 Test L5–1

The LOFT intermediate break experiment series L5 was designed to identify and evaluate the LOFT system thermal-hydraulic response during an intermediate size break LOCE. Experiment L5–1 was initially operated at thermal power of 45.9 MWt, vessel temperature difference of 27.0 K, mass flow rate of 308.2 kg/s at 14.93 MPa system pressure. The specific objectives of experiment L5–1 are to (1) obtain sufficient data to characterize the prevalent phenomena caused by an ECCS injection line rupture, (2) generate applicable data for use as a base line in the future planning of intermediate size break, (3) provide data to assess the analytical techniques used to model the principal phenoman of an intermediate size break. Also, data aquisition system was validated during this experiment L5–1.

3. Modeling and nodalization

3.1 Modeling

Break modeling, vessel and system modeling including boundary conditions are described in this section. The break for the IBLOCA was modeled with a motor valve whose rate of change for the normalized valve area was 14.0 unit per sec. The diameter of actual orifice used in L5–1 experiment was 0.047m [9] while a 0.004m diameter orifice was used for L3–7. The option of normal junction, nonhomogeneous, smooth area change and choking modeling applied (0000) were used to model L5–1 break.

The pellet stack length of core was 1.68m and five sets of 15x15 and four sets of 12x12 nuclear fuel assemblies existed [8]. Among 1300 fuel rods in the LOFT core, the central 204 fuels were modeled as a central hotter pin and the other 1096 fuels were described as a peripheral heat structure. The core basically was modeled as one flow channel which has six almost equal volume length of 0.221m. Two heat structures were used to model the central assemblies (12300000) and the peripheral (12310000) assemblies respectively. Both reflood and gap conductance option were not used since the primary pressure was kept higher than 1.0MPa during the period of interest and a tabular form of temperature vs. gap conductance data was used.

Some correction were made from the deck for LOFT L3–7 simulation [10]. For instance, core length was corrected to 1.68 from 1.98m. HPSI was modeled with a time dependent junction connected directly into cold leg. HPSI injection was initiated based on a set pressure, 10.6 MPa of hot leg pressure. Accumulator was modeled with "ACCUM", single volume and a valve. The initial accumulator water level was corrected to be 1.54m as in experiment and activated when the cold leg pressure was lower than 1.66 MPa. The model "ACCUM" was disconnected in the calculation when accumulator was emptied to overcome an accumulator related error. The flows from accumulator and LPSI were merged into a single volume ECCS header. The values for LPSI capacity were corrected based on the experiment L5–1 and LPSI was activated when the RCS pressure decreased to 1.08 MPa. Primary coolant pump was set to trip at 4.0 seconds. Thermal power was inputted with the combined data from fission and decay power [8]. Other hydraulic and thermal modelings for primary and secondary loop were

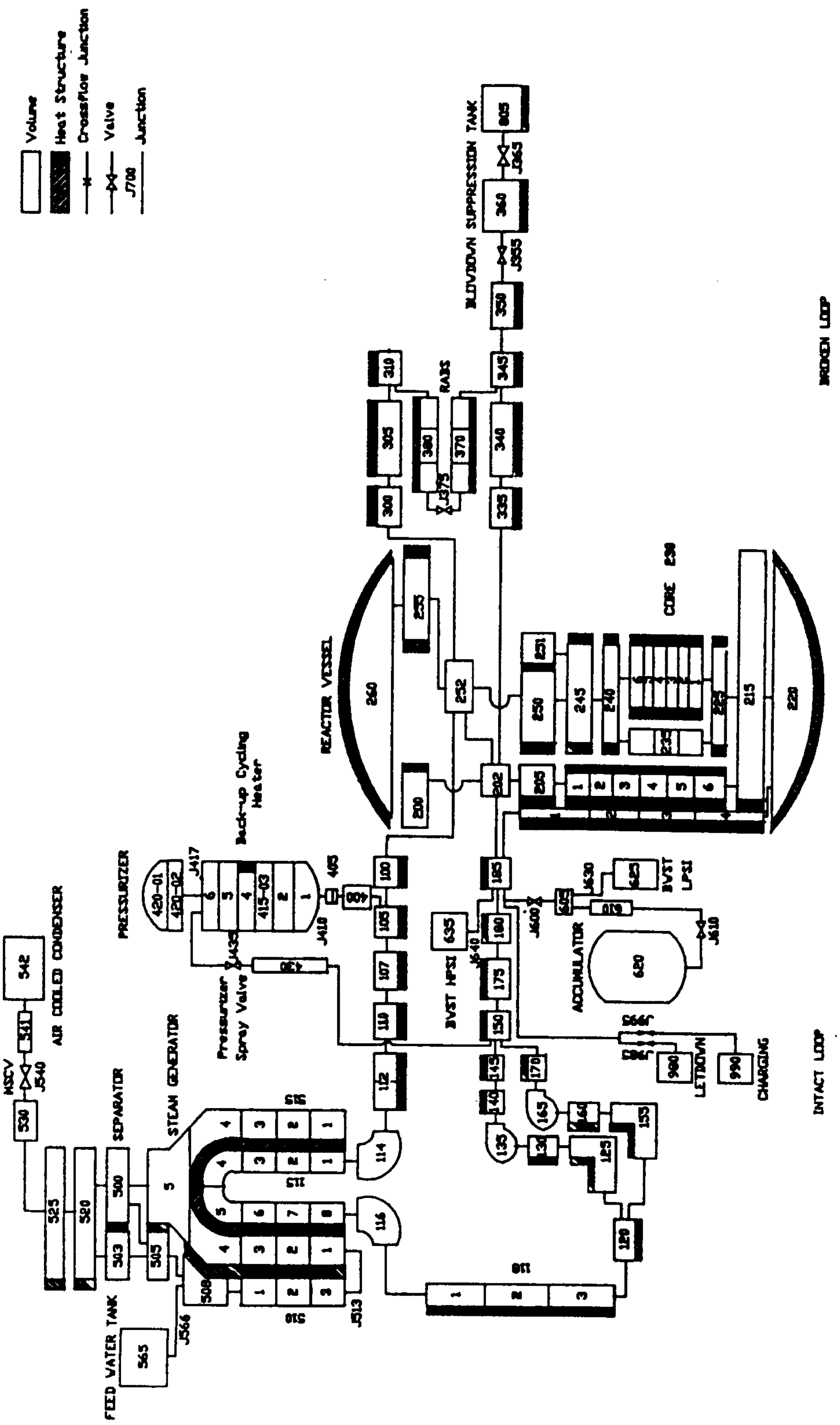

Figure 1. RELAP5 Nodalization for LOFT Test L5-1

conceptually the same as the one used for L3-7 SBLOCA assessment work [10].

The RELAP5/MOD2 nodalization diagram of the base case is shown in Figure 1. The nodalization has 130 volumes, 136 junctions, 143 heat structures and 793 mesh points. Basically the same nodalization concept as L3-7 was applied to L5-1. The nodalization for L3-7 [10] is the reference and few changes were added as described above. Figure 2 shows the comparisons of linear heat generation rate (kW/m) for experiment and calculation along the core height. The history of thermal power from fission and decay was properly described in the input deck.

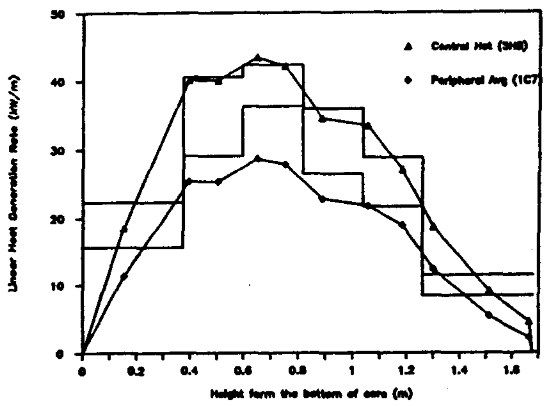

Figure 2. Axial profile of linear heat generation rate for Test L5-1

3.2 Initial and Boundary Conditions

The decks L51S12 and L51T12 in Cyber 170-875 were prepared for the purpose of assessment. Convergency was not achieved with the steady deck but the key values for the initial stages (Table 1) were generally within tolerable ranges at 300 second steady calculation. So, the values at 300 seconds were taken as the initial conditions for the following transient calculation. Table 1 shows the initial conditions of both experiment and calculation. The code predicted the primary system mass flow as 308.27 kg/s. hot leg temperature as 581.34K and cold leg temperature as 553.76K. Other T/H values for reactor vessel, pressurizer and accumulator were well predicted except the temperatures for the broken loop. The code overpredicted the broken loop hot leg temperature as 561.75K which was 7.45K higher than experiment. However, the discrepancy would not affect the results of later transient because of the small mass flow (about 2.88kg/s) rate through the broken loop. The major values for the steam generator secondary side were also fairly well predicted. The pressure was 5.00 MPa and steam mass flow rate was 3.15 kg/s initially.

Table 2 shows the sequence of events for experiment L5-1 and the base calculation. Within one second, reactor was scrammed and the secondary side inlet/outlet valves were closed and HPSI trip point was reached (10.6 MPa). HPSI injection was initiated with 2.48 seconds delay. Lowest in-core thermal excursion started at 184 and 182 seconds in experiment and base calculation. Accumulator (1.66 MPa) was injected at 185.8 and 189 seconds respectively. Maximum fuel-cladding temperature reached 715K at 198 seconds in experiment and 676K at 210 seconds in base calculation. So the code underpredicted the PCT by 39K. Finally LPSI (1.08MPa) flow was initiated at 201 seconds in calculation and 227 seconds in experiment.

4. Results and discussions from base case calculation

Table 3 summarizes the list of assessment parameters. It describes the identification of calculated and measured parameter in addition to measurement uncertainties. The corresponding figure numbers to the assessment parameters are also listed in Table 3. The system phenomena governing the response of L5-1 are classified as hyd-

Table 1 INITIAL CONDITIONS FOR EXPERIMENT L5-1

Parameter	Experiment L5-1 Measured Value (EDR [8])	REALP5/MOD2/Cycle 36.04 Calculated Value (L51S12) [I.C. of L51T12]
Primary System		
Mass flow(kg/s)	308.20	308.27
Hot leg pressure(MPa) [a]	14.93	14.87
Cold leg temperature (K)	552.30	553.76
Hot leg temperature(K)	579.10	581.34
Boron concentration(ppm)	669.00	–
Vessel DT(K)	26.80	27.58
Reactor Vessel		
Power level(MW)	45.90	45.77
Max LHGR(kW/m)	46.00	42.50
Pressurizer		
Vapor volume(m^3)	0.33	–
Liquid volume(m^3)	0.60	–
Liquid temperature(K)	615.00	614.48
Liquid level(m) [a]	1.13	1.10
Broken Loop		
Cold leg temperature(K)	549.20	557.40
Hot leg temperature(K)	554.30	561.75
Steam Generator Secondary Side		
Liquid level (m) [b]	0.27	0.287
Liquid temperature (K)	537.80	533.210
Pressure (MPa)	5.05	5.010
Mass flow(kg/s)	25.30	24.493
Accumulator A		
Liquid level (m) [c]	1.49	1.490
Pressure (MPa)	1.66	1.660
Liquid temperature (K)	308.20	308.200

[a] Out of specification, but did not impair results
[b] The liquid level is defined as 0.0 at 2.95m above the top of the tube sheet
[c] Liquid level is measured from 0.32m above the bottom of the accumulator vessel

raulic and thermal behavior for the purpose of further discussions. Hydraulic behavior can be explained primarily with discharge flow rate, depressurization, external ECCS flow, system inventory and core mixture level. Thermal behavior can be catagorized with the core thermal power, S/G secondary operation, core void and PCT. Since the break diameter is greater than 9 inch, it ex-

Table 2 SEQUENCE OF EVENTS FOR EXPERIMENT L5-1

Events	Time after Experiment Initiation(s)	
	Experiment L5-1 [8]	Calculation L51T12
Cold leg QOBV opened [a]	0.0	0.0
Reactor scrammed	0.17	0.06
Main feed pump tripped	0.17	0.07
Upper plenum reached saturation	0.20	0.25
HPSI trip point reached (10.6 MPa)	0.40	0.30
HPSI injection flow initiated	2.88	2.90
Primary coolant pump tripped	4.00	4.00
Broken loop cold leg reached saturation	10.50	11.00
Steam generator steam control valve closed	12.10	12.00
Pressurizer indicated empty	15.50	15.00
Primary pressure dropped below secondary	53.00	50.00
Fuel cladding thermal excursion started	108.40	141.00
Lowest in-core thermal excursion level reached	184.00	181.00
Accumlator A injection started	185.80	187.25
Maximum fuel cladding temperature reached	198.00	207.00
LPSI flow initiated	201.00	195.49

[a] Experiment initiation is defined to be the time when the broken loop cold leg pressure began to increase.

periences a relatively rapid depressurization process compared with a typical SBLOCA. Thus, the transient can be characterized by a blowdown/refill process occurred relatively slower than typical LBLOCA and the safety is mainly maintained by accumulator and LPSI flow rather than HPSI flow.

4.1 Hydraulic Behavior

The upper plenum pressure was depressurized very rapidly to 7 MPa in 20 seconds, and then, slowly depressurized at a rate of 1 MPa per 50 seconds until LPSI was initiated (Figure 3). The key T/H parameters of the secondary system such as the steam dome pressure was well predicted including the mass flow rates of steam generator inlet and outlet. The primary system inventory was well represented indicating that the discharge and incharge flows from ECCS were properly described (Figure 4). Figure 5 shows the HPSI flow rate matching with the experiment fairly well. Figure 6 shows the liquid level of accumulator and interestingly a 15 sec stagnant existed in 215 sec because of the repressurized system pressure (Figure 3) due to LPSI flow (Figure 7). Figure 8 shows the flow rate of ILHL and Figure 9 shows the reflooding rate, which influences the PCT most. Figure 9 indicates the negative flow after 37 sec till accumulator injects at 187.25 sec. The positive mass flow is less than 50kg/s in reflood phase. The slow depressurization occurred because the energy removed through the break (Figure 10) was less than the energy generated in

Table 3 List of Assessment Parameters (LOFT L5–1)

Description	Calculation	Measurement	Uncertainty
Primary System			0.140–0777
Pressure(Pa)	P 25001	PE–1UP–001A	EDR [8]
Steam Dome			0.087–0.077
Pressure(Pa)	P 53001	PE–SGS–001	
Steam Mass			0.28
Flow rate(kg/s)	MFLOWJ 54000	FT–P004–012	
Feedwater Mass			2.40
Flow Rate(kg/s)	MFLOWJ 56900	FT–P004–722	
Primary System			300.0
Inventory(kg)	CNTRVAR 72	Fig.4(EDR)	
ILHL			0.13
Density(Mg/m^3)	RHO 10001	DE–PC–002B	
BLCL			0.099
Density(Mg/m^3)	RHO 34501	DE–BL–002B	
HPSI Volume			0.014
Flow Rate(L/s)	MFLOWJ 64000	FT–P128–104	
Accumulator			0.007
Level(m)	CNTRVAR 4	LE–ECC–01A	
LPSI Volume			0.37
Flow Rate(L/s)	MFLOWJ 63000	FT–P120–085	
ILHL Mass			4.6
Flow Rate(kg/s)	MFLOWJ 10001	FT–P139–272	
Reflooding Mass			–
Flow Rate(kg/s)	MFLOWJ 23001	–	
Integrated Break			–
Mass Flow Rate(kg/s)	CNTRVAR 51	QLR [9]	
Pressurizer			–
Level(m)	CNTRVAR 2		
Steam Generator			–
Level(m)	CNTRVAR 1		
Reactor Water			–
Level(m)	CNTRVAR 10		4.2K
Cladding Temp(K)	2300110(7.5″)	T–5E8–015	at 600K
(Central, 15 inch)	2300210(19.5″)		″
Cladding Temp(K)	2300310(27.5″)	T–5F4–021	″
(Central, 21 & 26″)		T–5F4–026	″
Cladding Temp(K)	2300410(36.5″)	T–5D8–037	
(Central, 37 inch)			″
Cladding Temp(K)	2300510(45.5″)	T–5E8–049	
(Central, 49 inch)	2300610(52.5″)		
Cladding Temp(K)			″
(Peripheral, 26″)	2310310(27.5″)	T–4F9–026	
Cladding Temp(K)			″
(Peripheral, 45″)	2310510(45.5″)	T–4E8–045	
Void Fraction	VOIDF 23001–		–
	23006	–	–
Time Step, DT	CNTRVAR 81		
(sec)		–	–
CPU time	CPUTIME		
(sec)			

–Not available

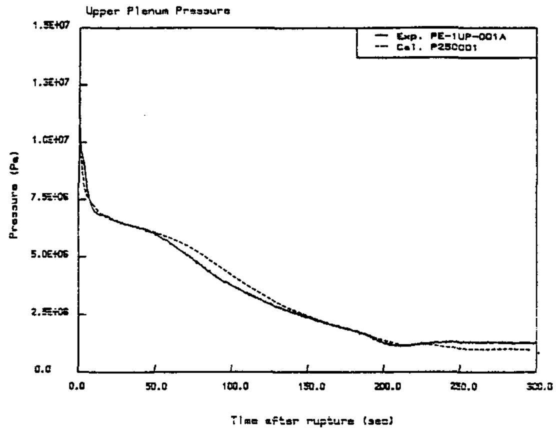

Figure 3. Upper plenum pressure transient

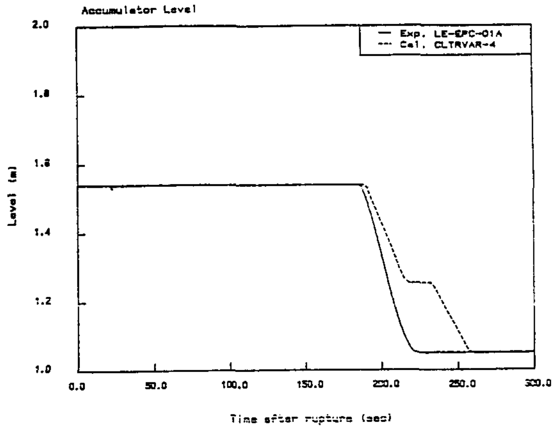

Figure 6. Accumulator level transient

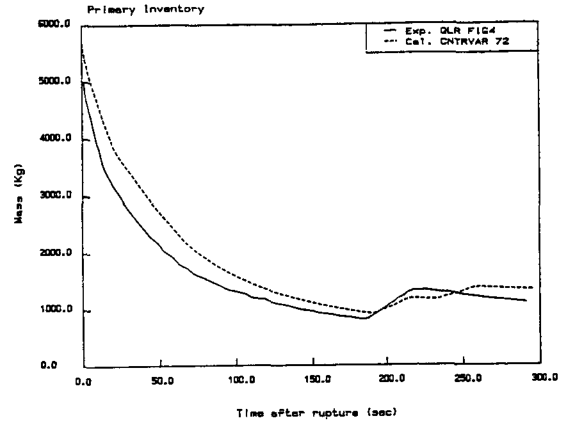

Figure 4. Primary system inventory transient

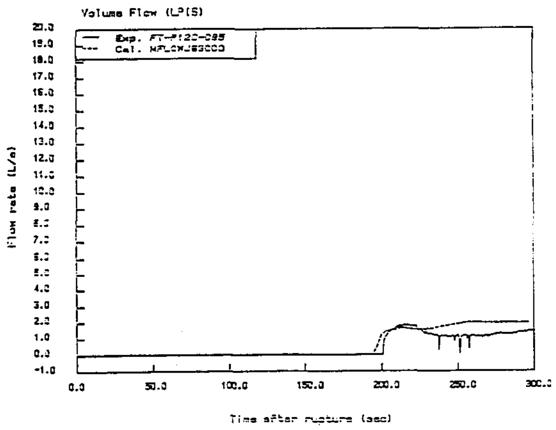

Figure 7. LPIS volume flow rate transient

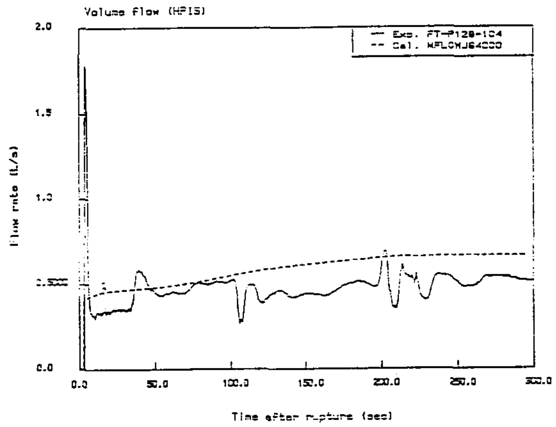

Figure 5. HPIS volume flow rate transient

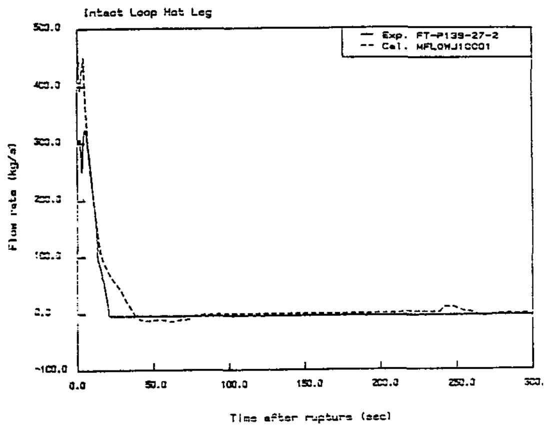

Figure 8. Intact Loop Hot Leg mass flow rate transient

the reactor core. After the interface between liquid and vapor fell below the break elevation, the rate of energy removal through the break increased. The RCS continued to depressurize after pressurizer was emptied until accumulator injected.

The calculations showed that a large volume of water supplied from accumulator and LPSI more than compensated for the loss of reactor coolant inventory and repressurized again at 217 seconds. It was verified again that accumulator and LPSI influenced more on safety than HPSI for this type of larger SBLOCA, i.e. IBLOCA transient. In core wise, the liquid was drained off at 180 seconds and started to be filled up again at 190 seconds due to the accumulator injection. Significant core uncovery occurred but the core quenches again due to the accumulator flow initiation.

Although the primary pressure decreased to 1 MPa in 200 seconds, the accumulator flow was injected at 186 seconds so that the fuel cladding temperature quickly dropped thereafter (Figure 12). The overestimated mass flow rates were caused by overpumping HPSI and LPSI flow rates. These overestimated flow rates caused a 17 second stagnant of accumulator water level at 217 second and it also affected the plateau of core

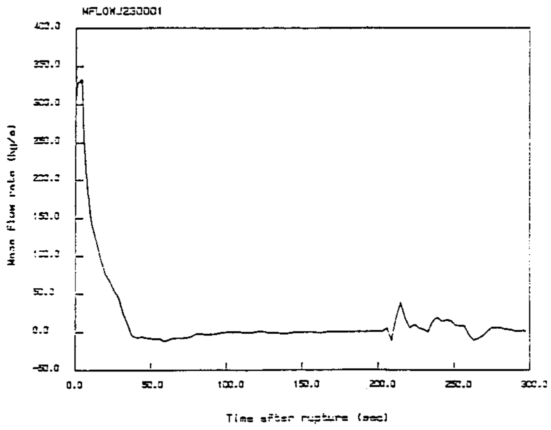

Figure 9. Reflooding mass flow rate transient

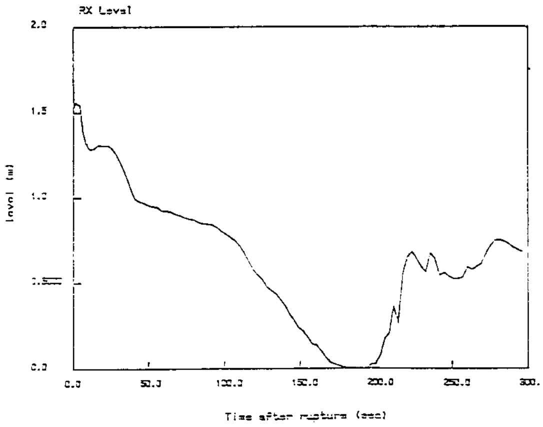

Figure 11. Reactor liquid collapsed level transient

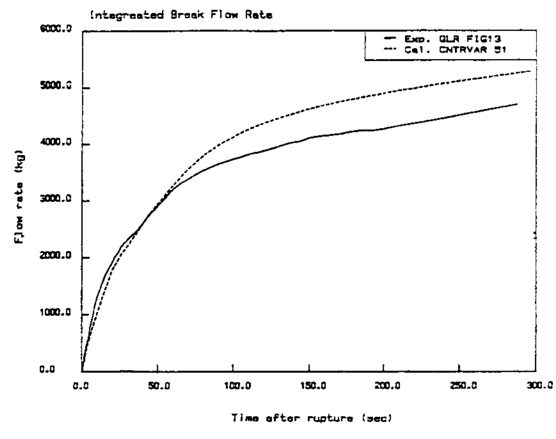

Figure 10. Integrated break mass transient

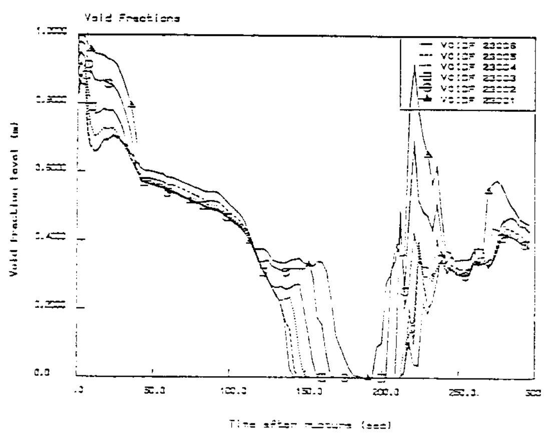

Figure 12. Liquid fractions along the core

mixture level. The base calculation predicted the key parameters of L5–1 experiment fairly well except two cases : the starting time of cladding temperature rise (dry-out) and earlier heat up in peripheral PCT measured. The base calculation predicted the start time of PCT rise 30 seconds later than the experiment (Figure 12). Figure 10 showed that the integrated break flow was predicted fairly well within maximum range of 200kg. Figure 4 indicated that the primary system inventory was initially overpredicted by 50kg and this affected to overpredict the inventory by 400–500kg over the transient. The overestimated water inventory probably caused the heatup to start later. Otherwise the low mass flux CHF correlation from modified Zuber [5] has a deficiency in the operating range because core mass flow was less than order of 20kg and flow area was 0.17 m^2. Providing that the discharge flow rate and the inventory were well predicted, Modified Zuber correlation overpredicted Q_{CHF} and needs to be examined for this low range mass flux and pressure. Also, fuel cladding temperature measurements in a peripheral assembly 4 at inch (T–4E8–45) indicated an early heat-up, quenching, reheat-up and final quenching (Figure 13). However, the calculation did not catch the early

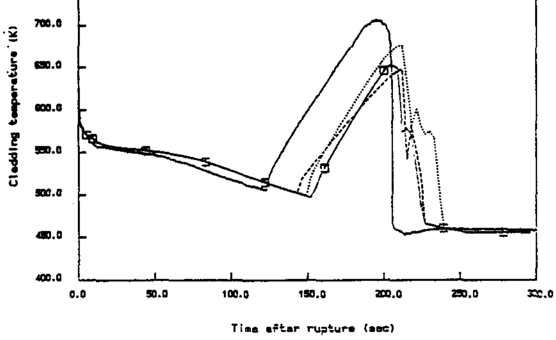

Figure 13. The effect of core nodalization sensitivity on PCT

heat-up.

Therefore, nodalization sensitivity study including two-flow channel effect on the peripheral fuel clad temperature is motivated to investigate whether the source of the deficiency comes from the code, modeling or experiment.

4.2 Thermal Behavior

History of thermal power from Reference 8 shows that the magnitude of fission power is very small after 10 seconds and thereafter the decay power, ranging from 2 MW to 1 MW, is dominant. A rapid core mixture level drop lead to a core uncovering. As two-phase circulation through the primary loop stops, the mixture levels in the S/G tubes drop steadily on both uphill and downhill side moving into a reflux cooling mode. The vessel mixture level also drops slowly during this S/G tube draining period until the mixture level reaches the bottom of the leg. Once the level reaches the bottom of the hot leg, it starts to decrease very rapidly because of the lack of a significant water supplied to the core from S/G. The mixture level affecting the fuel cladding temperature strongly decreases or increases depending upon loop seal clearing or degree of ECCS water supply. In this case, the mixture level increased again due to sufficient ECCS water supply.

Liquid void fraction of 230040000 became zero at 150 sec (Figure 14) and, then, thermal excursion started. At 198 seconds, maximum fuel cladding temperature of 715 K measured while the code predicted the start time of dry-out later by 25 second and the peak as 675K (Figure 12). At the central and 26 inch (T–5F4–026) location of fuel assemblies, the code still predicted the start of heatup later with the same heatup rate and underpredicted the peak by 15K. At the peripheral and 26 inch (T–4F9–26), the code overpredicted the peak by 150K due to highly estimated LHGR at

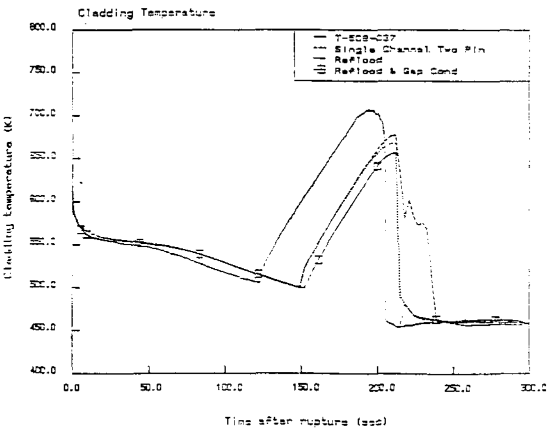

Figure 14. The effect of model option senstivity on PCT

the peripheral locations. The measured peak cladding temperature of 715K at 198 second was obtained at the central and 37 inch (T-5D8-37) measurement location. The calculation, at central 36.5 inch, with single flow channel and two heat structures underestimated the peak as 675K at 210 seconds while the experiment produced the PCT as 715K at 198 seconds.

Consequently, it showed again that compensating effects of discharge flow, decay power and external ECCS water supply decided the mixture level of the core. Considering heat transfer mechanism in core side, the core experienced a slow downward liquid drain off until 180 seconds (blowdown phase) and started to be filled up again from 190 seconds (refill/reflood phase). The first part can be considered as a slow blowdown phase and the second part as a refill or reflood period. Core mixture level increased again due to the flows from accumulator and LPSI. Accumulator and LPSI flow injection finally cooled down the fuel.

The effect of two flow channel and even single heat structure on PCT would be interesting to quantify its effect. The base modeling did not use the options of reflood and gap conductance model. Therefore, the effects of each options on PCT will be demonstrated as alternatives of model sensitivity studies.

5. Nodalization and sensitivity studies

From the discussions in the base calculations, two types (Case A and Case B) of nodalization and two types (Case C and Case D) of model option sensitivity studies were proposed to quantify its effect on a key safety parameter, PCT. The central PCT measured at T-5D8-37 was compared with HTTEMP 2300410 and a peripheral PCT measured at T-4E8-45 compared with HTTEMP 2310510. First, reflood option was added to the base modeling and, then, recalculation has been done with gap conductance option added as model sensitivity items.

5.1 Nodalization Sensitivity Study

5.1.1 Single Flow Channel and Single Heat Structure (Case A)

Case A, which modeled the core single flow channel and single heat structure, indicated the start time of clad temperature rise 10 seconds earlier and underpredicted the PCT by 25K in comparison with the base case. A later peak was calculated due to a stagnation of accumulator flow. Consequently, single pin modeling had advantage of predicting earlier dry-out time but disadvantage of PCT prediction when compared with the base case, which modeled the core as single flow channel and two heat structures (Figure 12).

5.1.2 Two Flow Channel and Two Heat Structures(Case B)

Case B, two flow channel and two heat structures, showed a later heatup and still lower PCT but better than Case A. However, a second peak was observed and not appeared in the experiment, which was directly due to the stagnant flow from accumulator. Two flow channel and two pin model did not improve the central PCT prediction but the peripheral PCT was predicted better. Figure 13 showed an earlier measurement peak, which was not predicted in calculations. The earlier peak probably was caused by a liquid deentrainment during the experiment and the modeling concept based on one-dimensional could not catch the earlier heatup.

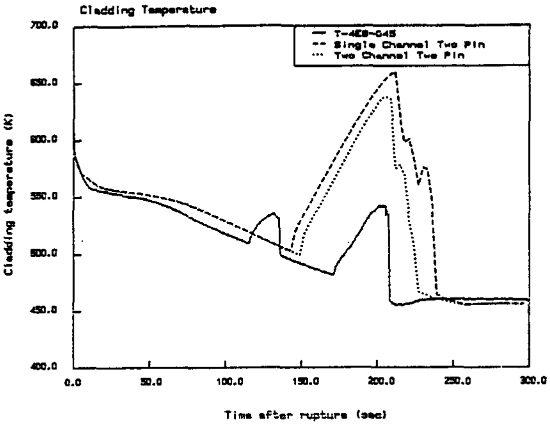

Figure 15. The effect of two flow channels on peripheral clad temperature

5.2 Model Sensitivity Study

5.2.1 Reflood Option Added (Case C)

Case C, reflood option only added, predicted the PCT 10K lower than the base case (Figure 15). The reflood initiation pressure at Volume 230060000 was set as 2.0 MPa because the overall system pressure did not go below 1.0 MPa in experiment and to turn on the reflood option as in the experiment. Case C did not include the accompanying peak during quenching, which was experienced in the base calculation. This straight quenching without the peak behaved more closely to the experiment than the base case. Therefore, using the reflood option is recommended even for the transient process pressure about 2.00 MPa.

5.2.2 Reflood and Gap Conductance Option Added (Case D)

Case D, both reflood and gap conductance option used, indicated the start time of clad temperature rise 10 seconds later and even lower PCT by 25K than the base (Figure 15). The second peak during quenching was observed but the magnitude was negligible. Both models contributed to calculate the PCT lower than the base case. The higher gap conductance values, the lower PCTs were calculated. This study also indicated that the gap conductance data given in the base deck were lower than the data calculated by gap conductance model. Since the heatup rates of the two cases were similar and the PCT was underestimated, it is not recommended to use the gap conductance option for this type IBLOCA; and, instead, tabular form used in the base case is more preferable.

6. Conclusions

RELAP5/MOD2 Cycle 36.04 code was assessed using LOFT L5-1 IBLOCA test data. A base case calculation including single flow channel and two heat structures was carried out without using reflood and gap conductance models as a reference case. Two cases of nodalization studies and two types of model sensitivity studies were conducted to quantify their effects primarily on PCT. Case A modeled the core as single flow channel and single heat structure while Case B modeled the core as two flow channels and two heat structures. Case C used reflood option over the base modeling and Case D added gap conductance option to Case C. Based on the results from the given scope, the following conclusions can be made.

1) Using LOFT IBLOCA test data L5–1, a base case calculation with a base nodalization was successfully executed and matched fairly well with the LOFT IBLOCA L5–1 experimental data.

2) The code with base nodalization showed that fuel clad temperature rise occurred 25 sec later and underpredicted the PCT by 40K in comparison with the experiment. The modeling with a single flow channel and a single heat structure improved the start of clad temperature rise (heatup) by 10 seconds but underpredicted the PCT worse by 50K, compared with the experiment. The model with two-channel and two heat structures predicted the PCT a little better than Case A by 5K but heatup started later than the base case by 10 seconds. Therefore, the base modeling, a single flow channel and two heat structures, proves to be better than the Case A and the Case B to predict the PCT for LOFT IBLOCA L5–1 transient.

3) The base modeling did not predict the early peak occurred at 125 sec as in temperature measurement at T–4E8–045 (Figure 30) and the limitation of one dimensional modeling caused not to predict the earlier peak observed in the experiment. The model with two channels and two pins improved to predict the PCT in the peripheral assemblies by 20K compared with the base case ; but, still the code overpredicted the reflood PCT at the peripheral assemblies because the modeling assumed higher LHGR.

4) Model sensitivity studies revealed that the case with reflood model option underpredicted the PCT more than the base case by 10K. The case with both reflood and gap conductance option underpredicted the PCT even worse than the base case by 20K. Consequently, if both model options were added, then lower PCT was calculated. The higher the gap conductance values, the lower PCTs were calculated. This means that the gap conductance data inputted to the base deck are lower than the values calculated from gap conductance model. So it is recommended to use reflood option and not to use gap conducatnce option additionally for the IBLOCA application.

5) 25 seconds later dry-out time encountered in calculating the core thermal behavior was not significantly improved through the four proposed sensitivity studies although Case A improved the start time of dry-out by 10 seconds. The overestimated primary system inventory seems to cause the later heatup. Otherwise, this later heatup occurance could be due to poor prediction of CHF occurance at low mass flux and that operating pressure condition in models rather than improper nodalization scheme. Chen [12] and Aksan [13] also reached similar conclusions to this problem. So, the originally proposed L5–1 base modelling is the optimum for LOFT IBLOCA Test L5–1 simulation among the tested cases.

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