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Comparison Of CATHARE2 And RELAP5/MOD3 Predictions On The BETHSY 6.2 TC Small-Break Loss-Of-Coolant Experiment

Young-Jong Chung, Jae-Jun Jeong, Won-Pyo Chang, and Dong-Su Kim
Korea Atomic Energy Research Institute
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CATHARE2와 RELAP5/MOD3를 이용한 BETHSY 6.2 TC 소형 냉각재상실사고 실험결과의 해석

정영종 · 정재준 · 장원표 · 김동수
한국원자력연구소
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Abstract

Best-estimate thermal-hydraulic codes, CATHARE2 V1.2 and RELAP5/MOD3, have been assessed against the BETHSY 6.2 tc six-inch cold leg break loss-of-coolant accident (LOCA) test. Main objective is to analyze the overall capabilities of the two codes on physical phenomena of concern during the small break LOCA, i.e. two-phase critical flow, depressurization, core water level depression, loop seal clearing, liquid holdup, etc. The calculation results show that the two codes predict well both in the occurrences and trends of major two-phase flow phenomena observed. Especially, the CATHARE2 calculations show better agreements with the experimental data. However, the two codes, in common, show some deviations in the predictions of loop seal clearing, collapsed core water level after the loop seal clearing, and accumulator injection behaviors. The discrepancies found from the comprision with the experimental data are larger in the RELAP5 results than in the CATHARE2. To analyze the deviations of the two code predictions in detail, several sensitivity calculations have been performed. In addition to the change of two-phase discharge coefficients for the break junction, fine nodalization and some corrections of the interphase drag term are made. For CATHARE2, the change of interphase drag force improves the mass distribution in the primary side. And the prediction of SG pressure is improved by the modification of boundary conditions. For RELAP5, any single input change doesn't improve the whole results and it is found that the interphase drag model has still large uncertainties.

요 약

본 연구에서는 BETHSY실험장치에서 수행한 6″ 소형 냉각재 상실사고(LOCA) 실험을 최적 열수력 코드인 CATHARE2 V1.2와 RELAP5/MOD3를 이용하여 계산했다. 본 연구의 주 목적은 소형 LOCA시 관심을 가지는 주요 물리현상인 이상 임계유동, 감압과정, 노심수위 감소, loop seal clearing 등에 대한 두 코드의 소형 LOCA 계산모의능력을 평가하는 것이다. 두코드는 이상 유동현상의 전개 경향이나 발생시점을 비교적 잘 예측하는 것으로 나타났고, CATHARE2의 경우가 실험과 더 잘 일치

했다. 그렇지만 두 코드는 loop seal clearing 현상, loop seal clearing 발생후의 노심수위, accumulator 유량거동 등의 예측에는 약간의 편차를 보였는데, 편차의 정도는 RELAP5가 CATHARE2 보다 더 큰 것으로 나타났다. 두 코드의 편차요인을 보다 상세히 분석하기 위하여 계면 마찰력, mesh 크기, 파단노즐 junction에서의 방출계수(Discharge coefficient)등에 대 하여 민감도분석을 수행하였다. 그 결과 CATHARE2의 경우는 계면 마찰력을 증가시킴으로써 감압과정시 일차계통의 질량분포, 즉 증기발생기 입구 공동(SG inlet plenum)에서의 차압과 Crossover leg의 차압이 개선되었으며, 증기발생기 외측 열전달계수를 증가시킴으로써 증기발생기의 압력변화를 개선할 수 있었다. RELAP5의 경우는 어떤 하나의 입력변수를 변화시켜서 과도기의 결과를 개선할 수 없었으며 다만, 계면 마찰력 모델링에 여전히 많은 불확실성이 내포되어 있음을 확인했다.

1. Introduction

For realistic simulation of complex two-phase flow phenomena under the conditions of LOCAs, several best-estimate thermal-hydraulic codes, such as RELAP5, TRAC-PF1, ATHLET, and CATHARE2, have been developed. These have been assessed with various separate- and integral-effect tests through the developmental and independent assessment programs. However, comparisons of the best-estimate code predictions with experimental data still show wide range of deviations; it was learned from the ISP-27 (International Standard Problem-27) that different users either with the same code or with different codes could obtain wide ranges of different results [1]. These are considered due to, first of all, code deficiencies and so called user effects [2]. Therefore the concern as a user must be whether the correct application of the code is achieved within its capability. Since it is known that there exist large uncertainties in best-estimate code predictions, rigorous, and systematic assessment activities are still undergoing.

For the similar reason, KAERI has been performing the assessments of best-estimate codes CATHARE2 [3, 4] and RELAP5 [5]. In the present study, BETHSY 6.2 tc, which corresponds to a six-inch cold leg break LOCA, is analyzed as one of the assessment activities using both CATHARE2 1.2E and RELAP5/MOD3 codes [6]. Main objective of this work is to analyze the overall prediction capabilities of the two codes on small break LOCA simulations. Physical phenomena of concern are two-phase critical flow, depressurization, core water level depression, loop seal clearing, liquid holdup, etc.

2. Facility And Transient Description

2.1. BETHSY Facility

BETHSY is a scaled-down model of a three-loop 900 MWe FRAMATOME pressurized water reactor (PWR) designed for the study of accident transients [7].

The primary coolant system (PCS) shown in Fig.1 consists of the pressure vessel, an external downcomer, three identical loops, steam generators (SGs), and a pressurizer. The pressurizer is connected to either the hot leg of loop 1 or loop 2. The PCS vessel can be operated at a condition of up to 17.2 MPa and 673 K.

The reactor core is composed of 428 full-length indirectly heated rods and 29 guide thimbles. It is powered with a 3 MW electric supply, which corresponds to the decay heat level on the BETHSY scale. The rods represent the average rod behavior and, thus, the radial peaking factor is equal to one. The downcomer consists of the upper external pipe and the lower annulus surrounding the lower plenum of the reactor vessel. All bypass flow paths except "cold to hot leg" path are properly modeled.

Each reactor coolant pump (RCP) operate at the scaled conditions. The general configuration of SG is similar to that of the SGs of the reference plant. Each SG contains 34 inverted U-tubes of the same radial dimensions and height stepping as those of the reference SG, thus providing a scaled heat transfer area between primary and secondary sides. The SG can operate at the pressure of up to 8 MPa.

The safety injection system has the same capabilities of the reference PWR, which consists of the high pressure safety injection system, accumulators, and low pressure safety injection system. In addition a trace heating system is installed to compensate for the increased environmental heat losses.

More than 1000 channels are used to measure transient parameters that include temperature, pressure, differential pressure, flow rate, and void fraction. The sampling rates are 1 to 5 Hz. Measurement error bands are well described in the BETHSY measurement system [8].

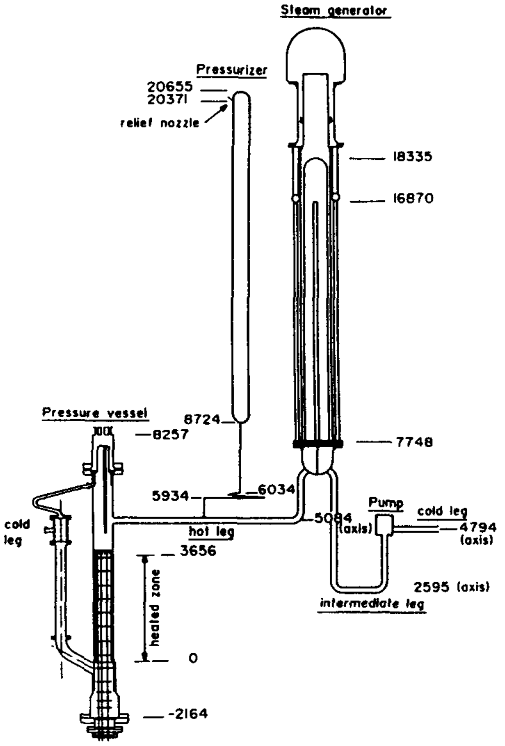


Fig. 1. The Primary Cooling System of BETHSY (Elevations in mm)

2.2. 6.2TC Transient Description

The BETHSY 6.2TC test [9] corresponds to a six-inch cold leg break LOCA of the reference plant. The test was performed to analyze the physical phenomena during a small break LOCA, and to compare the behaviors of two different facilities of different scales, i.e., BETHSY and LSTF, in the course of an intermediate cold leg break.

Initial experimental conditions are listed in Table 1. Side-oriented break nozzle(D = 15.48 mm, L/D = 10) is located on the cold leg of the loop 1 where the pressurizer is attached, and the accumulator on the loop 1 is isolated.

Major event chronology is as follows:

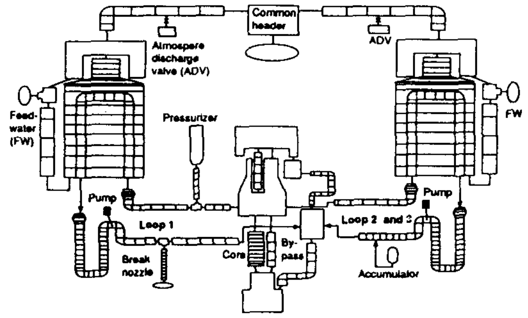
t = 0 s opening of the break valve,
  – the trace heating was stopped,
t = 8 s scram signal occurred(pressurizer pressure < 13.0 MPa),
  – core power was maintained at 2863 kW for 53 s, then followed the JAERI conservative curve,
  – RCPs were stopped,
  – the condenser was stopped,
  – normal feedwater supply was stopped,
  – SG discharge valve setpoint was set to 2 MPa,
t = 12 s safety injection signal occurred (pressurizer pressure < 11.7 MPa),
  – no action, the HPSI was not operated,
t = 341 s accumulator opening signal occurred (pressurizer pressure < 4.2 MPa),
  – opening of accumulators 2 and 3 (with time delay 4 s),
t = 948 s accumulator 3 stopped by level criterion,
t = 976 s accumulator 2 stopped by level criterion,
t = 2179 s test stopped (pressurizer pressure < 0.7 MPa).

Table 1. Initial Conditions of BETHSY 6.2TC

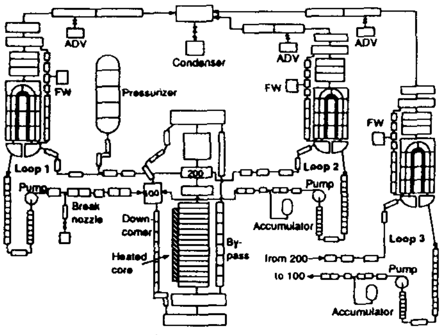
Parameter	Experiment	CATHARE2	RELAP5
Power, kW	2863±30	2840	2863
Prz. press., MPa	15.38±0.15	15.47	15.38
Prz. level, m	7.45±0.2	7.70	7.65
Pump speed, rpm	238±6	238	238
Core inlet temp., K	557.2±0.4	558.2	557.7
Core exit temp., K	588.2±0.4	589.5	588.9
PCS coolant inventory, kg	1984±50	1978.7	1976.0
SG pres., MPa	6.84±0.07	6.89	6.81
SG level, m	11.1±0.05	12.0	10.5
FW. water temp., K	523.2±.2	523.2	523.2
Bypass flow, %	0.28	0.24	0.28
Heat loss, kW	54.82	54.82	57.71

3. Code And Model Description

The BETHSY facility [10] is nodalized in detail enough to capture important two-phase flow processes, such as core water level depression, loop seal clearing, and transient coolant distribution in the PCS. Since these are chiefly governed by manometric head balance between the reactor vessel and the crossover legs, fine nodalizations are employed for some of the vertical pipings, of which elevations are lower than that of the horizontal part of the hot leg, in both CATHARE2 and RELAP5 input models. Figure 2 shows hydrodynamic input models for the two codes.



(a) CATHARE2 nodalization



(b) RELAP5/MOD3 nodalization

Fig. 2. CATHARE2 and RELAP5 Nodalizations for BETHSY 6.2TC

3.1. CATHARE 2 Input Modeling

CATHARE2 input is composed of several modules ;axial, volume, tee, boundary, etc. Each module is separated from another module by a junction. The junction is a topological notion used to separate two elements. No special physical point is attached to the junction. The axial module calculates an one-dimensional, six-equation, two-fluid model. It is used to describe main primary pipes, core channels, a downcomer, and SG U-tubes. The volume module calculates a punctual two nodes model. This module has to be used in two cases; to describe large volume where gravity effect is dominant, for example, head, upper plenum and lower plenum and to connect together several modules. The tee module is a junction module use to connect a pipe to another pipe. It is used for connection of the pressurizer surge line to the hot leg or the break nozzle to a main pipe of the loop. The boundary condition element is an element which can be put at the extremity of a pipe, of a volume or of a tee and allows the imposition of one or more hydraulic conditions for each phase. These boundary conditions can be defined at the inlet or outlet of an element.

The CATHARE2 input for BETHSY 6.2TC consists of 21 pipe modules, 9 volumes, 4 tee modules, and 4 boundary conditions, which results in 317 hydrodynamic cells (see Fig.2). The intact two loops are agglomerated into a single representative loop because the two loops experience very similar transitions. The reactor core region is modeled with 17 mesh axial module. The downcomer inlet annulus is modeled with a volume module, which connects the upper bypass, the cold leg, and the downcomer. The break nozzle is represented by 16 mesh axial module. The heat transfer between structure and coolant is modeled with wall module by defining appropriate geometry and boundary conditions. The environmental heat loss is also simulated.

3.2. RELAP5 Input Modeling

The RELAP5 input model consists of 251 volumes, 258 junctions, and 283 heat structures. Three coolant loops are individually modeled. Active core region is modeled with 14 volumes; seven regions separate by the eight spacer grids are divided into equal-length two volumes. However, for the SG U-tube, only eight volumes are used because six-inch break is sufficiently large to remove the decay heat through the break and thus the effect of SG heat transfer on the PCS is presumed to be not great.

To accurately simulate liquid holdup in the SG inlet plenum, the counter-current flow limitation (CCFL) options are applied at the junctions from the horizontal portion of the hot leg to the vertical portion of the hot leg. The Wallis form of the CCFL equation is used [11, 12]: The slope and gas intercept are 0.785 and 0.55, respectively.

The RCPs and accumulators are represented with RELAP5 special component models. The ECC Mixer model is not employed since it is evaluated to be ineffective in this case [13]. For the break junction the discharge coefficients of 0.85, 1.2 and 0.96 are used for subcooled water, saturated two-phase, and single-phase vapor discharge, respectively. Passive heat structures are also modelled to take account of the environmental heat losses.

In general, the RELAP5 input model herein adopts fine nodalization for the lower portion of BETHSY and coarse for the upper portion in comparison with the various input models shown in the final report of ISP-27 [1].

4. Results Of Simulations And Discussions

4.1. Base Case Calculation

The steady state is obtained by simulating a stabilizing null transient of several hundreds seconds, of which results are used as initial conditions of transient calculations. In order to achieve the steady-state conditions consistent with the experimental data, some input variables of the two codes are calibrated through repeated calculations: (i) The downcomer-to-upper head bypass flow is so small in both the CATHARE2 and RELAP5 results that the orifice area at the bypass path is increased to attain a flow rate of 0.28% system flow rate. (ii) The SG heat transfer is underpredicted in the RELAP5 results. This is corrected by decreasing the heated equivalent diameter of U-tube outside [5]. The resulting steady-state data are listed in Table 1. Both

CATHARE2 and RELAP5 results show good agreements with the experimental data.

Transient calculations are done with the initial conditions described above. Major event chronology is compared with the experimental data in Table 2. Figures 3 through 14 show transient behaviors of important parameters. In general, both CATHARE2 and RELAP5 predict well the accident trends. As shown in Figures, the results of CATHARE2 show better agreement with the measured data, while those of RELAP5 generally show fast evolutions. In the following sections, the calculation results are compared and discussed.

Depressurization and Break Flow In Fig.3, the pressurizer pressures are compared. CATHARE2 calculations agree well with the measured data throughout the experiment. RELAP5 begins to overpredict the depressurization rate at about 280s and the discrepancy reaches the maximum about 1.8 MPa at about 350s. This difference seems to be due to overprediction of break flow.

As shown in Fig.4 and 5 the calculated break flow rates and the integrated break flow of the two codes remain within the measurement error band. However, the transition from low-quality to high-quality two-phase blowdown is delayed in the RELAP5 results and, as a result, the integrated break flow is overpredicted in comparison to that of CATHARE2. Until 300s, RELAP5 overpredicts the integrated break flow by about 95kg comparing with that of CATHARE2. This difference corresponds to about 5% of the initial PCS coolant inventory and is not changed until the end of experiment. Another reason of the faster depressurization may be the poor prediction of core void distribution by RELAP5. As shown in Fig.6, almost the upper one third of the active core is uncovered from about 280s to about 320s in the RELAP5 calculations and, thus, steam generation at the core is underpredicted during the period, which in turn evokes the faster depressurization.

Collapsed Water Level in Core Figure 7 shows the collapsed core water levels. Core uncovery appears three times in the experiment and

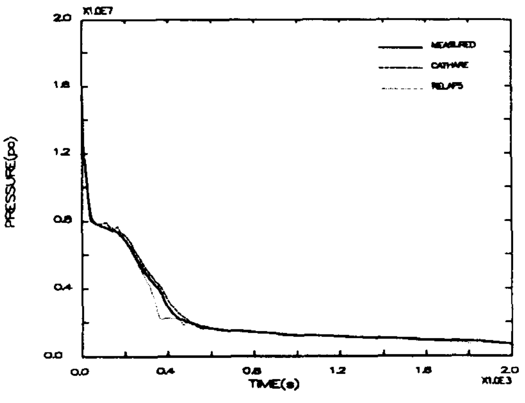


Fig. 3. The Pressurizer Pressures.

Table 2. Chronology of Major Event

Parameter	Experiment	CATHARE2	RELAP5
Reactor scram, s	8.0	5.3	6.9
Safety injection, s	12.0	11.2	14.5
Loop seal clearing, s	134	130	138
Primary/secondary pressure reversal, s	172	188	176
Acc. 2 injection, s	345–948	360–774	315–828
Acc. 3 injection, s	345–976	360–774	315–786
Prz. press. < 0.7 MPa, s	2179	2111	1856

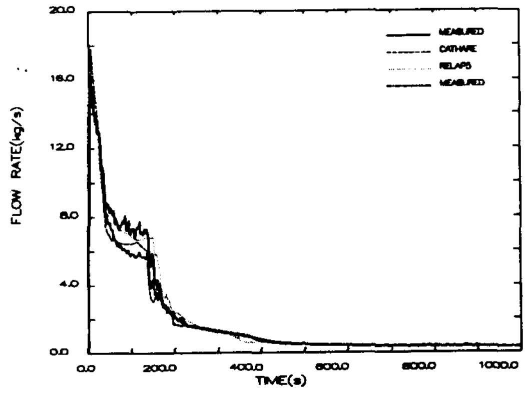


Fig. 4. The Break Flow Rates.

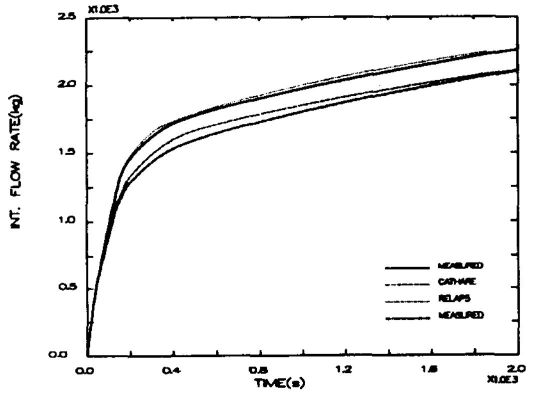


Fig. 5. The Integrated Break Flow Rates

simulations. The evolution of collapsed core water level can be divided into four distinct different periods; (i) low-quality two-phase blowdown period until the loop seal clearing, (ii) high-quality two-phase blowdown period until the beginning of accumulator injection, (iii) accumulator injection period, and (iv) the boil-off period until the end of experiment. As shown in Fig.7, CATHARE2 predicts well the collapsed core water level behavior except for the second period, but RELAP5 predicts some deviations of the collapsed core water level after the loop seal clearing.

During the first period, the collapsed core water level rapidly decreases by low-quality two-phase break

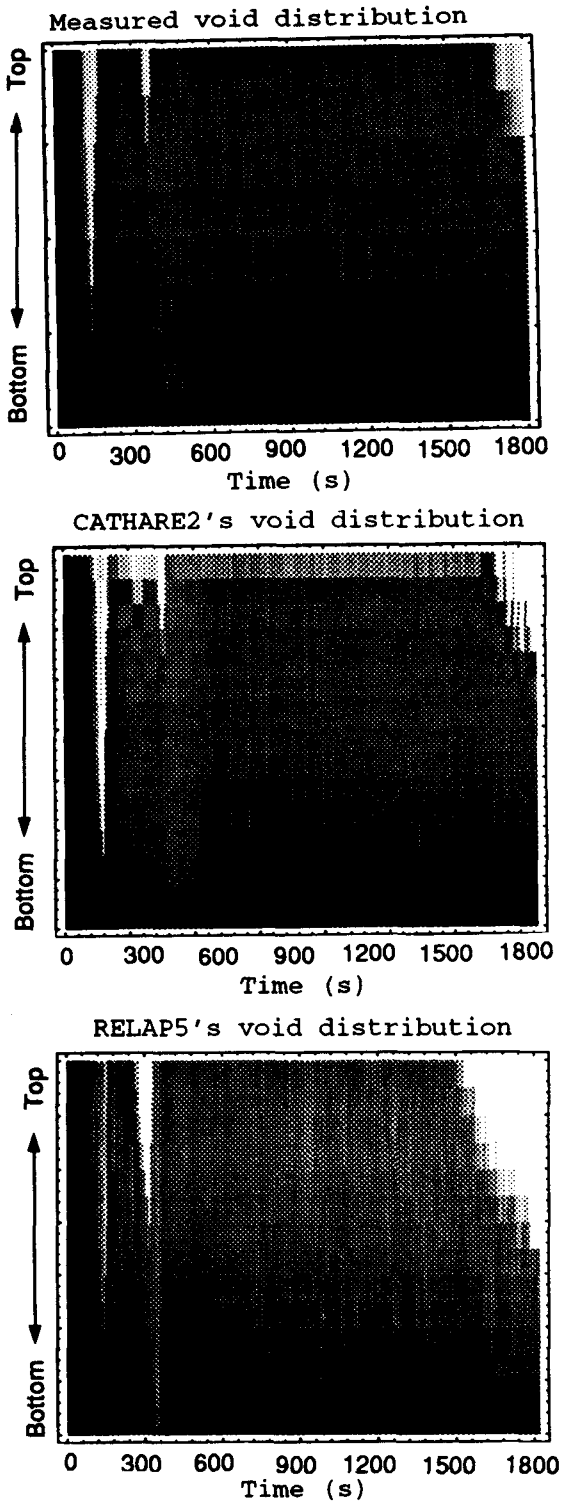


Fig. 6. Void Distributions at The Reactor Core(White: Void Dark: liquid)

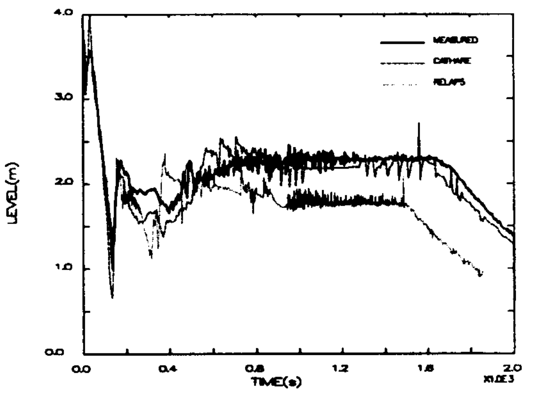


Fig. 7. The Collapsed Core Water Levels.
(z=0.0m Bottom of core, z=3.656m Top of core)

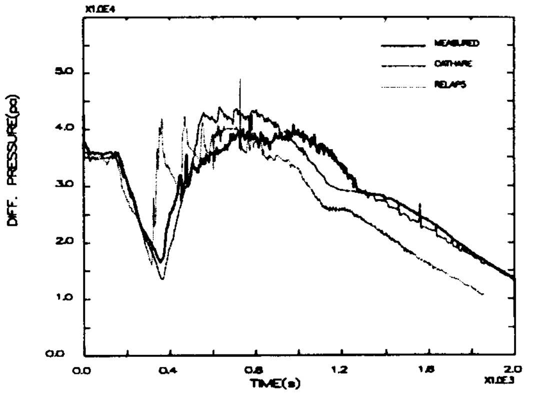


Fig. 8. The DPs at The Downcomer.

flow and subsequent flashing of core coolant. Minimum water level occurs just before the loop seal clearing. By manometric head balance between the reactor core and the crossover legs, the minimum level is well predicted to be about 1.0m by two codes.

The collapsed core water level of the second period is determined by manometric head balance between the downcomer and the core. Both CATHARE2 and RELAP5 underpredict the collapsed core water level of this period. After the loop seal clearing, the downcomer head pushes fluid back into the core(see Fig.8) and the collapsed core water level increases instantaneously. The DPs in the Fig.8 is the differential pressure between the core inlet nozzle and the downcomer outlet. Rapid depressurization begins again since the break is uncovered and then the collapsed core water level continues to decrease until the actuation of accumulator. During the second period, the two codes underpredict the collapsed core water levels. These seem to be the incomplete loop seal clearings; that is, the remaining liquid in the upflow side of the crossover legs depresses the collapsed core water level.

During the third period, the collapsed core water level increases due to makeup of the accumulator water. In general, the collapsed core water level of CATHARE2 shows reasonable agreement with the experimental data, but that of RELAP5 shows large deviations due to the earlier, large amount of accumulator injections.

The fourth period is characterized by redistribution of coolant, boiloff, and monotone level decrease. CATHARE2 well predicted the collapsed core water level. However, RELAP5 underpredicted it by about 0.5m. The deviation of about 0.5m core water level is equivalent to about 19kg of coolant. In recognition of about 100 kg of the integrated break flow difference, such a level deviation is inevitable.

Liquid Holdup at the SG inlet plenum One of phenomena that affects the core water level depression is the liquid holdup in the upper region of the PCS such as hot leg and SG inlet plenum. The liquid in the SG inlet plenum and upflow side of U-tubes run back into the reactor vessel by gravity, but the liquid can drain only against the counter-current steam flow. The drain rate is predicted by two codes. Figure 9 shows the measured and calculated differential pressures in the SG inlet plenum which is the difference between pressure at the inlet of SG plenum and pressure at the bottom of SG tube sheet. Both codes early predict the drain of SG1 inlet plenum right after the loop seal clearing. These are due to the underestimation of the interphase drag (see

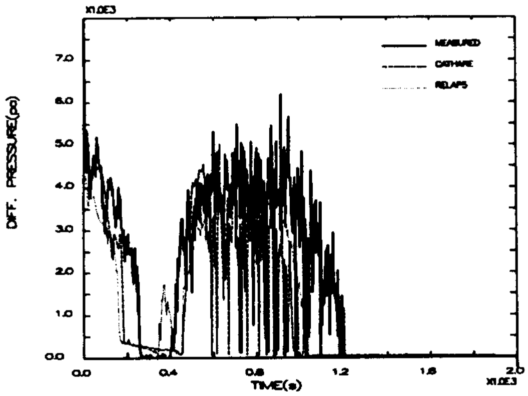


Fig. 9. The SG1 Inlet Plenum DPs.

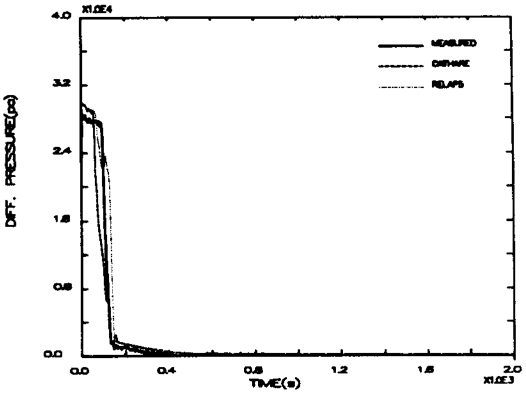


Fig. 10. The DPs at The Down Flow Side of The Crossover Leg 1.

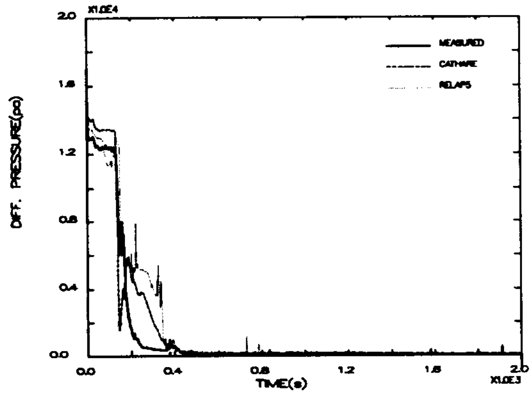


Fig. 11. The DPs at The Upflow Side of The Crossover Leg 1.

CATHARE2 sensitivity calculation). Significant liquid holdup is predicted during the accumulator injection period. Both codes well predict trends, but the timing and magnitude of holdup are not accurate. In the CATHARE2 results, the differential pressure during the accumulator injection is underpredicted and abnormally oscillates between 0 and 40 HPa.

Loop Seal Clearing After the break opens, the upper portion of the PCS gradually fills with steam and finally liquid seals are left in the crossover legs and in the reactor vessel and downcomer. These liquid seals make a blockage of steam flow along the loop toward the break. As a result, the vessel upper plenum and hot legs are pressurized, which causes manometric depressions in both the liquid level in the downflow side of the crossover legs and the reactor vessel.

The loop seal clearings are well illustrated by the differential pressure(DP) behaviors of the downflow and upflow sides of the crossover legs. In the experiment the loop seal clearings of all the loops occurred almost simultaneously at 134s. Figure 10 and 11 indicate that CATHARE2 and RELAP5 predict the loop seal clearings occurred at 130 and 138s, respectively. The DPs at the upflow side of the crossover leg is the differential pressure between the RCP inlet and the crossover leg bottom. The DPs at the downflow side is the differential pressure between the crossover leg bottom and the SG outlet plenum nozzle. The three loops showed the same behaviors in the calculations. In the CATHARE2 and RELAP5 results, the downflow side is completely drained, but the upflow side is partially drained as shown in Fig. 11. Complete drain is established after about 200s. This effect is significant because the remaining liquid in the upflow side of crossover legs pushes down the core water level until it is completely cleared. CATHARE2 also predicted incomplete loop seal clearing, but its magnitude is relatively small.

Core Uncovery and Heatup Core uncovery can not be directly measured. Instead, local void fractions can be retrieved from the eight differential pressure measurements installed in the active core region. Transient void distributions along the core are compared in Fig.6. The dark indicates liquid phase and the white indicates vapor phase. Core uncovery occurred three times in the experiment, and the two codes also predict three times of core uncovery. The void distributions of the CATHARE2 results agree well with the experimental data. In the RELAP5 calculations, the duration of the first core uncovery at about 140s is very short, the second uncovery at about 300s is long-lived and deep, and the third uncovery begins too early. These high void fractions of the RELAP5 predictions are, in general, due to the over estimation of the interphase drag force.

Since the predictions of core heatup depend on those of core uncovery, CATHARE2 predicts well the heatup. On the other hand, RELAP5 doesn't predict the first core heatup at 2.1m and predicts earlier the third heatup as shown in Fig.12.

Accumulator Injection Due to the faster depressurization in the RELAP5 calculations, the accumulator injection also begins earlier than in the experiment and CATHARE2 calculations. Figure 13 shows the integrated accumulator flows. The two codes predict intermittent injection behaviors rather than the continuous behavior as measured, and the depletions of accumulators are premature in both the CATHARE2 and RELAP5 calculations. Times elapsed during 50% injection of the accumulator water in the CATHARE2 and RELAP5 calculations are about 120s and about 50s, respectively. In contrast, about 190s is elapsed in the experiment. This mis-prediction directly effect on the downcomer and core water level behaviors (see Fig.7 and 8).

Steam Generator Behavior As soon as the safety injection signal occurs, the condenser and feedwater are isolated. Then the SG pressure increases up to the setpoint of safety valves 7.2 MPa, because the primary-to-secondary heat transfer is still active. After 172s, the secondary side pressure exceeds the primary side pressure, and reverse heat transfer begins. Figure 14 shows that both CATHARE2 and RELAP5 overpredict the pressure from about 200s. This differences result from inaccurate predictions of environmental heat loss and U-tube heat transfer(see CATHARE2 sensitivity calculation).

Computation Times For comparison of computation times, the source programs of CATHARE2 V1.2 and RELAP5/MOD3 are compiled and executed

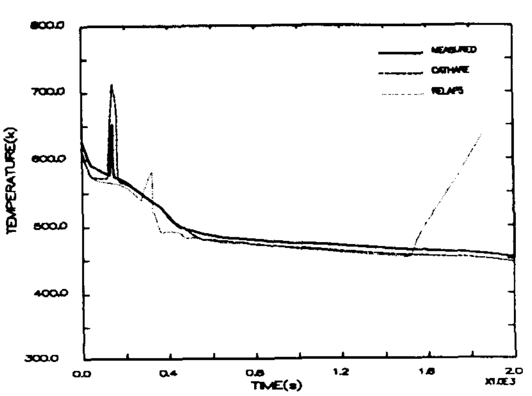


Fig. 12. The Rod Surface Temperatures at 2.1m.

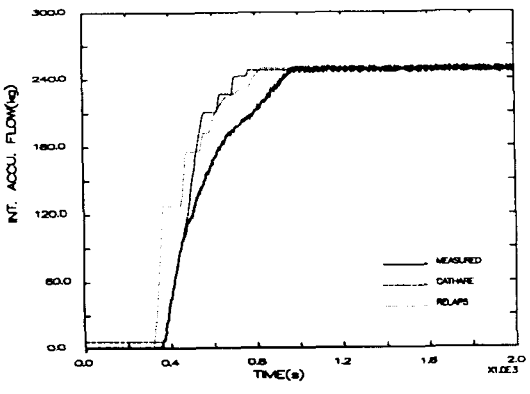


Fig. 13. The Integrated Accumulator Flows.

on both the Solbourne 5/600 workstation and the Convex C3410ES computer. Computation times are summarized in Table 3. When executed on the vector machine Convex, the computation times of CATHARE2 and RELAP5 take 17 and 40% of those on the Solbourne, respectively. This indicates that some modifications of the current RELAP5/MOD3 version are desirable for taking advantage of the vector machines.

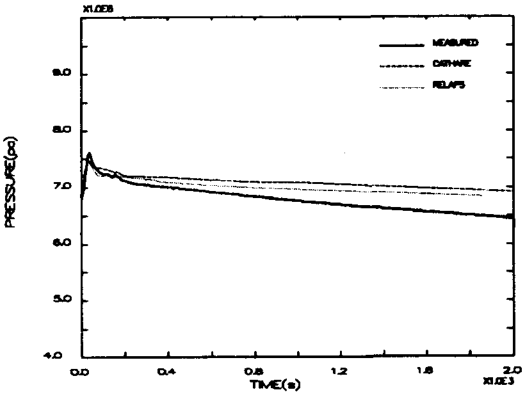


Fig. 14. The SG 1 Pressures.

4.2. Sensitivity Calculations

CATHARE2 Sensitivity Calculations The deviations of the CATHARE2 predictions seem to be underprediction of interfacial drag forces. To improve the CATHARE2 predictions, several sensitivity calculations have been performed and the results are summarized as follows:

(i) Interfacial drag force: To improve the primary mass distribution, the interfacial drag force is increased by half than that of the base case. Figures 15 through 17 show the results of sensitivity calculations. Figure 15 shows the SG1 inlet plenum DPs. The liquid holdup behavior after loop seal clearing occur is improved but it is still under predicted until the end of the accumulator injection. Figure 16 shows the DPs at the upflow-side of the crossover leg. Complete drain is established at simultaneously with the experiment. The drain rate at the crossover leg is increased than that of the base case because the interfacial drag force is increased. Figure 17 shows the collapsed core water level. The collapsed core water level at the high void region is underpredicted in comparison with that of the base case.

(ii) Heat loss to environment: After the SG is isolated by safety injection signal, the heat transfer of

Table 3. Comparison of Computation Times

Code	CATHARE2		RELAP5/MOD3	
Computer	Solb	Conv	Solb	Conv
No. of volumes	317	317	251	251
Problem time, s	1998	1997	1856	1868
CPU time, s	2.180e5	3.768e4	1.394e5	5.637e4
No. of time step	48234	46153	93594	95441
Average time step, s	0.0414	0.0433	0.0198	0.0196
CPU time/prob. time	109.1	18.87	75.1	30.2
Grind time[a], s	0.0143	0.00258	0.00593	0.00235
Max. time step[b], s	1.0	1.0	0.02	0.02

Solb: Solbourne 5/600, Conv: Convex C3410ES

[a] (CPU time)/(No. of volumes)/(No. of time steps)

[b] User input

SG takes place only at the U-tube and environment. In this period, the environmental heat loss is important to predict the SG pressure. The heat transfer coefficient from SG wall to environment is increased to improve the prediction of SG pressure. The calculation result is shown in Fig.18. As shown in Fig.18 the modified heat transfer coefficient is more suitable for BETHSY 6.2TC test.

(iii) Nodalization of the loops: The number of mesh for the SG inlet plenum and the crossover legs upflow side are increased from 7 and 5 to 14 and 10, respectively. Calculation results are similar with the base case calculation. But the CPU time is increased by 18% than that of the base case.

RELAP5 Sensitivity Calculations The deviations of the RELAP5 predictions are conceived to primarily result from the overprediction of the break flow, the incomplete loop seal clearing, and the overpredictions of interphase drag forces(the underprediction of interphase drag forces is also found in the SG inlet plenum DP predictions). To improve the RELAP5 results, the input model is

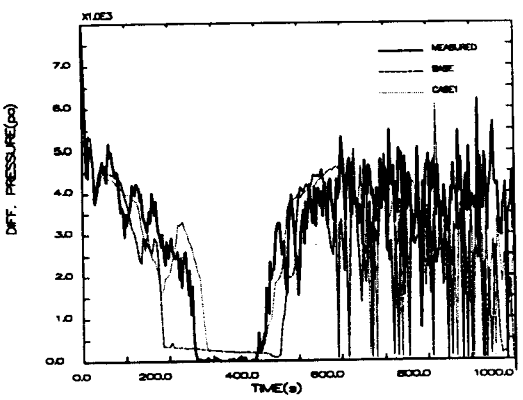


Fig. 15. The SG1 Inlet Plenum DPs (CATHARE2 Sensitivity Calculation)

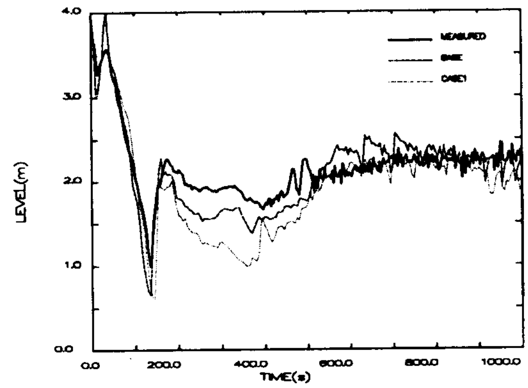


Fig. 17. The Collapsed Core Water Level (CATHARE2 Sensitivity Calculation)

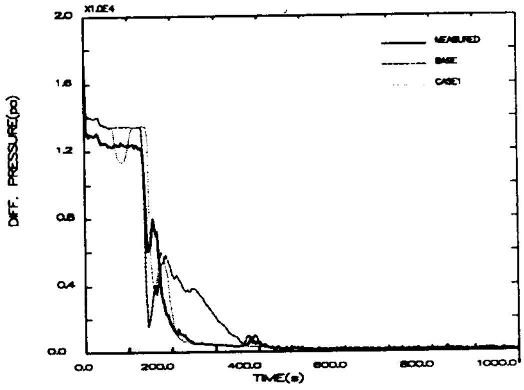


Fig. 16. The Upflow Side DPs of The Crossover Leg1 (CATHARE2 Sensitivity Calculation)

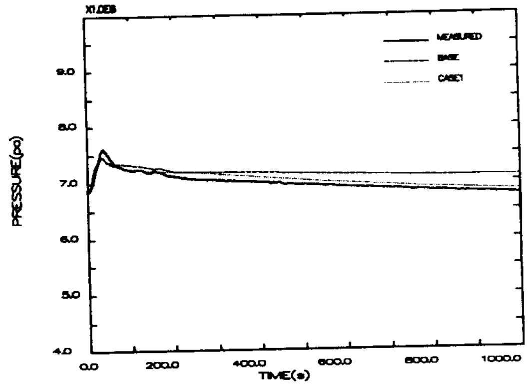


Fig. 18. The SG 1 Pressures (CATHARE2 Sensitivity Calculation)

carefully reviewed and then several sensitivity calculations have been conducted. The findings are summarized as follows:

(i) Interphase drag model: On the basis that the interphase drag forces are generally overestimated, they are reduced by half. Significant changes are found in the calculation results and, in general, the calculation results seemed to be improved. The integrated break flow until 1800s is reduced by 29kg in comparison with that of the base case. This is due to the earlier transition from low-quality to high-quality two-phase discharge at the break. The prediction of the loop seal clearing is not improved. Figure 19 shows the collapsed core water level behavior; it remains almost unchanged until about 350s and, after then, increased by 0.3m comparing with the base case results. Figure 20 shows the SG1 inlet plenum DP behaviors, which is further underestimated during the accumulator injection period, as expected. Although this correction is not based on a physical principle, it reveals that the interphase drag model has still large uncertainties.

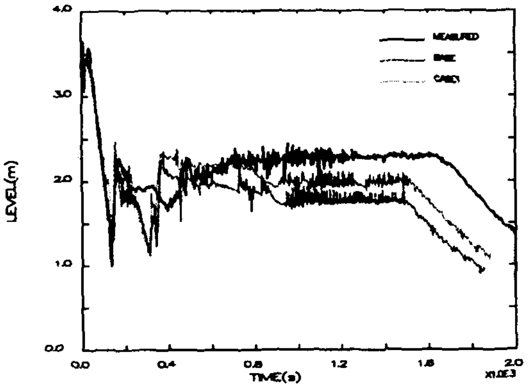


Fig. 19. The Collapsed Core Water Level (RELAP5 Censitivity Calculation)

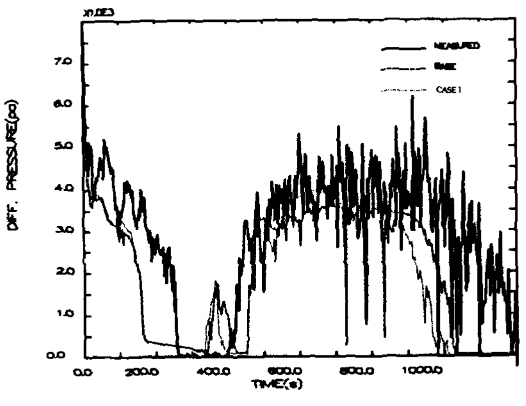


Fig. 20. The SG1 Inlet Plenum DPs (RELAP5 Sensitivity Calculation)

(ii) Two-phase discharge coefficient for the break junction: Increasing the discharge coefficient yielded more deep first core water level depression and fast evolution of the transient. Decreasing the coefficient reduced the break flow and extended the duration of low-quality two-phase discharge period. In any way, the integrated break flow remained unchanged and the system behaviors are almost the same with those of the base case calculation.

(iii) Nodalization of the upflow side of crossover legs: The number of volumes for the upflow side is increased from 7 to 10. Calculation results showed no differences, that is, the incomplete loop seal clearing is not resolved.

5. Concluding Remarks

The calculation results show that both CATHARE2 and RELAP5 predict well both in the occurrences and trends of major two-phase flow phenomena observed during a small break LOCA. In the present simulation, the CATHARE2 calculations show better agreements with the experimental data.

Some discrepancies are also found; the two codes, in common, showed some deviations in the predictions of loop seal clearing, collapsed core water level after the loop seal clearing, and accumulator injection behaviors. Generally the deviation magnitudes are found larger in the RELAP5 results than in the CATHARE2.

The sensitivity calculations using CATHARE2 show that the increase of the interfacial drag force improve the primary mass distribution for the BETHSY 6.2TC test, i.e. modification of interfacial drag force leads to a good capability in the prediction of primary side mass distribution during the depressurization transient. After the beginning of accumulator injection, the differences found in the RELAP5 calculations are presumed to result from uncertainties in the interphase drag model. The RELAP5 sensitivity calculations show that the interphase drag model has still large uncertainties.

References

1. P. CLEMEN, T. CHATAING and R. DERUAZ., "ISP−27 BETHSY Experiment 9.1b 2″ Cold Leg Break Without HPSI and with Delayed Ultimate Procedure", Comparison Report, OECD Nuclear Energy Agency (1992).
2. S.N. AKSON and F. D'Auria, "Investigations on the user effects for the thermal-hydraulic transient system codes:Case studies", Proc. 5th Intl. Mtg. on the Reactor Thermal Hydraulics NURETH-5, Sep. 21−24, Salt Lake City, American Nuclear Society (1992).
3. F. BARRE and M. BERNARD, "The CATHARE code strategy and assessment", Nucl. Eng. Des. Vol. 124, pp.257−284 (1990).
4. C. SARRETTE, "User's Manual of CATHARE2 V1. 2E", STR/LML/EM/91-07, CEA, Grenoble (1991).
5. K.E. CARLSON, R.A. RIEMKE, S.Z. ROUHANI and W.L. WEAVER, "RELAP5/MOD3 code manual (draft)", NUREG/CR−5535, EG&G Idaho (1990).
6. D.S. KIM, et al., "Developmemt of Safety Analysis Technology", KAERI/TR372/93, Korea Atomic Energy Research Institue (1993).
7. R. DERUAZ, "BETHSY General Description", Note SET/LES/90−97, CEA, Grenoble (1990).
8. P. GULLEY and R. DERUAZ, "BETHSY Measurement System", Note SET/LES/87−27, CEA, Grenoble (1987).
9. D. JUHEL and G. BRIDAY, "BETHSY Test 6.2TC 6−inch Cold Leg Side Break Comparative Test", Note SETh/LES/90−112, CEA, Grenoble (1990).
10. P. BAZIN "BETHSY:Data Base", Note SET/LES/87−28, CEA, Grenoble (1988).
11. G.B. WALLIS, One-Dimensional Two-Phase Flow, p.336, McGraw-Hill, New York (1969).
12. S.M. SLOAN, Y. HASSAN "A Study of RELAP5/MOD2 and RELAP5/MOD3 Predictions of a Small-Break Loss-of-Coolant Accident Simulation conducted at the ROSA-IV large-scale test facility", Nucl. Tech. Vol. 100;p p.111−124 (1992).
13. C.J. CHOI, A.R. PAUL and R.R. SCHULT, "Assessment of RELAP5/MOD3 version 7 based on the BETHSY 6.2TC", Proc. 5th Intl. Mtg. on the Reactor Thermal Hydraulics NURETH−5, Sep. 21−24, Salt Lake City, American Nuclear Society (1992).