Journal of the Korean Nuclear Society
Volume 28, Number 2, April 1996

A Study on the Vent Path Through the Pressurizer Manway and Steam Generator Manway under Loss of Residual Heat Removal System During Mid-loop Operation in PWR

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(Received October 2, 1995)

가압경수로의 부분충수 운전중 잔열제거계통 기능 상실사고시 가압기와 증기발생기 Manway 유출유로를 이용한 사고완화에 관한 연구

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한국원자력연구소

(1995. 10. 2 접수)

Abstract

The present study is to analyze an integral test, BETHSY test 6.9c, which represents loss of RHRS accident under mid-loop operation. Both the pressurizer manway and the steam generator outlet plenum manway are opened as vent paths in order to prevent the system from pressurization by removing the steam generated in the core.

The main purposes are to gain insights into the physical phenomena and identify sensitive parameters. Assessment of capability of CATHARE2 prediction can be established the effective recovery procedures using the code in an actual plant.

Most of important physical phenomena in the experiment could be predicted by the CATHARE2 code. The peak pressure in the upper plenum is predicted higher than experimental value by 7 kPa since the differential pressure between the pressurizer and the surge line is overestimated. The timing of core uncovery is delayed by 500 seconds mainly due to discrepancy in the core void distribution. It is demonstrated that openings of the pressurizer manway and the steam generator manway can prevent the core uncovery using only gravity feed injection. Although some disagreements are found in the detailed phenomena, the code prediction is considered reasonable for the overall system behaviors.

요 약

본 연구는 불란서 CEA에서 수행한 부분충수 운전 중 잔열제거계통 기능 상실사고 실험인 BETHSY 실험 6.9c를 CATHARE2 코드를 이용하여 분석하였다. BETHSY 6.9c 실험은 잔열제거계통 기능 상실시 가압기와 증기발생기 출구공동의 Manway를 통해 노심에서 발생한 증기를 제거하여 계통의 가압 정도를 시험한 것이다.

연구의 주요목적은 사고발생시 예상되는 주요 물리적 현상의 이해와 과도기에 영향을 미치는 민감변수를 확인하고 CATHARE2 코드의 예측능력을 평가하여, 실제원전의 유사사고 해석에 대한 신뢰성을 확보하는 것이다.

연구결과 CATHARE2 코드는 실험을 통해 관측된 주요 물리적 현상들을 타당하게 예측하였으나, 가압기와 밀림관의 DP를 과대 예측하여 원자로 상부공동의 최대압력을 실험보다 약 7kPa 높게 예측하였다. 노심 노출시간도 노심에서 기포율 분포를 비현실적으로 예측하여 실험보다 약 500초 지연되었다. 실험과 코드의 모의결과를 통하여 노심 노출은 중력주입에 의한 냉각수 보충만으로 충분히 회복될 수 있음을 확인하였다. CATHARE2 코드는 비록 상세한 현상들에 대해 다소 불확실성을 내포하였으나, 전반적인 거동분석에는 타당한 것으로 판단된다.

1. Introduction

In case of PWR, for the purposes of maintenances and inspections of such components as steam generator U-tubes, reactor coolant pump seal devices, and pressurizer, it is operated with reduced coolant level in the Reactor Coolant System (RCS). The liquid level is maintained at the mid-level of primary loop horizontal legs while the upper parts of the primary system are occupied by either steam or non-condensable gas. This operation is called mid-loop operation.

Under this operation, Residual Heat Removal System (RHRS) plays a major role to remove decay heat. Loss of RHRS accident during the mid-loop operation has been experienced several times in the world [1]. Major causes of this accident are known as failure of RHR pump, mis-operation of the main isolation valve, loss of AC power, false signal actuation, etc. Without a proper countermeasure for the event, it leads to heat-up and boiling of coolant in the core and eventually could result in core damage. It is particularly serious because of small coolant inventory. The countermeasures may differ according to plant conditions and transient management processes, for examples, gravity injection of Refueling Water Storage Tank (RWST), forced injection of Low Pressure Safety Injection (LPSI) system, or heat exchange with secondary side of steam generator as illustrated in the reference [2].

The Probabilistic Safety Assessment (PSA) results also indicated that Core Damage Frequency (CDF) under the shutdown condition could almost comparable with that under full power operation and the loss of RHRS during mid-loop operation among the accidents under shutdown, significantly contributes to the shutdown CDF [3, 4]. The transient of loss of RHRS during mid-loop operation depends on various factors, such as reactor type, non-condensable gas existence, steam generator availability, nozzle dame installation, vent location, accumulator actuation, and RWST location and actuation, etc.

Due to increasing concern of the accident, several integral experiments [5, 6] have been performed to understand physical phenomena during the accident. At the same time, capability of best estimate code is also assessed using the experimental results for reliable analysis. As an example, RELAP5 has been used to simulate the loss of RHRS accident during mid-loop operation, which was performed at Large Scale Test Facility (LSTF). Only a part of the experiment was calculated instead of the entire transient (3500 seconds in total of 15790 seconds) because most of important phenomena took place during the early period of the transient [7]. For a utility response to GL 88-17, Westinghouse corporation performed the analyses using the TREAT-NC code [8].

In this regard, the objective of the present study is to analyze an integral test concerned with the loss of RHRS during mid-loop operation, performed at BETHSY facility [9] in order to gain insights into the physical phenomena and identify sensitive parameters in the accident. To these ends, the best estimate thermohydraulic code CATHARE2 [10] has been used for the analysis. Physical phenomena of concern are pressurization rate, timing of core uncovery, decay heat removal capacities through the vents, and the effect of core inventory make-up depending on vent paths. The assessment of the overall code prediction capabilities may provide an important basis to establish the effective recovery procedures using the code in an actual plant.

2. BETHSY Facility and Transient Description

2.1. BETHSY Facility

BETHSY is integral test facility whose purpose is an investigation of PWR accident transients [9]. Its main objectives are to contribute to physical bases of either event-oriented or state-oriented PWR Emergency Operating Procedures (EOP) and to provide experimental data for code assessment. BETHSY, which includes all the corresponding circuits and systems, is a scaled-down model (volume 1 : 100, height 1 : 1) of a three-loop 900 MWe Framatome PWR. The RCS consists of a pressure vessel, an external downcomer, three loops, steam generators and a pressurizer. The secondary system consists of steam generator shell side, steam line, and main feed and auxiliary feed water systems. Besides, there are safety injection system, break system, and trace heating system.

The location of hot and cold leg nozzle has different elevation. The hot leg is positioned that its axis is the same elevation as the PWR hot leg nozzle axis. The cold leg has been chosen for a better simulation of water head in both the downcomer and the up-flow side of the intermediate legs to preserve the elevation of the lower bound of cold leg nozzles. As a result, the cold leg axis is 29cm lower than that of the hot leg. The pressure vessel and the steam generator can operate at the pressure up to 17.2, 8 MPa, respectively. The safety injection system has the same capabilities of the reference PWR, which consists of the high pressure safety injection system, the accumulators, and the low pressure safety injection system. In addition, a trace heating system is installed to compensate the increased environmental heat losses comparing with those of reference plant.

2.2. BETHSY Test 6.9c Transient Description

BETHSY Test 6.9c [11] is simulated the accident scenarios following loss of RHRS accident during mid-loop operation by two manway valve openings, i.e. the pressurizer and the steam generator 1 outlet plenum manways open. The test was performed to investigate the physical phenomena under conditions of very low pressure and low power. The concerns were observations of liquid hold-up both in a pressurizer and in a surge line, liquid entrainment in a hot leg tee branch, and the validity of gravity feed type countermeasures. The other objective was to verify the validity of CATHARE code under such transients.

Initial experimental conditions are listed in Table 1. The primary pressure was kept at atmospheric pressure. The temperature in the primary system was sat-

Table 1. Initial Conditions for LOSS of RHRS

Parameter	Test 6.9c	
	experiment	calculation
Upper plenum pressure(MPa)	0.104±0.003	0.104
Core power (kw)	0.0	0.0
Pump speed (rpm)	0.0	0.0
Primary total mass (kg)	1085±15	1085
Pressure vessel mass(kg)	700±9	698
Hot leg 1/2/3 void (−)	0.59	0. 51
	0.55	0. 51
	0.52	0. 51
Cold leg 1/2/3 void (−)	0.0/0.0/0.0	0.0/0.0/0.0
Upper plenum liquid temperature (K)	375±2	375
Lower plenum liquid temperature (K)	374±2	375
Hot leg 1/2/3 liquid temperature (K)	375±2	374
	374±2	374
	372±2	374
Cold leg 1/2/3 liquid temperature (K)	366±2	366
	366±2	366
	365±2	366

uration temperature of its pressure except in cold legs. To simulate mid-loop operations, the water level in the reactor vessel was located close to the axis of the hot legs and the cold leg temperatures were 8 K lower than those of hot logs. The core power was maintained at 0 kw throughout initial condition.

The whole transient is divided into three phases according to major phenomena. The first phase is the period when the two phase level is located close to the axis of hot legs. During the second phase, the two phase level in the vessel is dropped below the active core. The third phase corresponds to RCS refilling period until liquid fills hot legs.

3. Code and Model Description

CATHARE2 is a best estimate thermal hydraulic code for analysis of Loss Of Coolant Accidents (LOCA) as well as operational transients. The code has been developed by joint efforts of CEA, EDF and Framatome in France. It is fully modular in order to be able to represent an analytical experiment as well as a complex geometry like a power plant [10]. CATHARE contains five basic modules such as pipe module, capacity module, tee module, branch module, and boundary condition module. A pipe module is used to describe main primary pipes, core channels, a downcomer, and steam generator U-tubes with 1-dimensional, 2-fluid model. The capacity module has to be used in two cases; to describe large volume where gravity effect is dominant, for example, dome, upper plenum and lower plenum or to connect several modules together. The tee module connects a pipe to another pipe, for instance, a pressurizer surge line to a hot leg or a break nozzle to a main pipe. The boundary condition module is an element which can be put at the extremity of a pipe, a volume or a tee, and it allows the imposition of one or more hydraulic conditions for each phase. These boundary conditions are to be defined at both the inlet and outlet of a component.

For test 6.9c input, modelling is modified from the small LOCA input data [12] as followings; upper head to downcomer bypass line, two capacity modules for pressurizer instead of one due to numerical reason, pressurizer upper part for manway nozzle and steam generator side crossover leg for steam generator manway nozzle. CATHARE input for test 6.9c as shown Fig. 1 has 25 components with 419 meshes for 3 loops. Generally, vertical parts which are related with liquid hold-up, liquid entrainment, and nozzle outlet are nodalized with fine meshes; for example, surge line and pressurizer manway nozzle.

The active core is modeled with axial module of 16 meshes. The downcomer inlet annulus is modeled with a capacity module which connects the cold legs, the upper head bypass, and the downcomer. The pressurizer manway nozzle is modeled with 26 meshes and the minimum mesh size is 0.3 mm at the nozzle outlet to account for a high velocity. The environmental heat loss is also modeled to simulate experimental trace heating. The U-tubes are modeled by wall operator to consider heat transfer to air filled in the secondary side of steam generators.

The calculation of the initial conditions is carried out by use of SINK and SOURCE operator at lower head to adjust vessel mixture level [13]. Finally, the initial conditions given in Table 1 are obtained. The core power was set at 0 kw as given in the experiment and the liquid temperature difference between core inlet and outlet is as small as 1 K. This initial state is implemented by using PERMINIT and stabilize transient options in CATHARE2. To simulate mid-loop conditions, the cold leg temperature is adjusted 8 K less than that of hot leg by WRITE operation [13].

4. Analysis Results and Discussion

Following the procedure set in the experiment, the transient in the analysis begins as the manway valves are opened. At the same time, the core power also turns on 140 kw from 0 kw within 15 seconds and thereafter the power keeps the constant value until

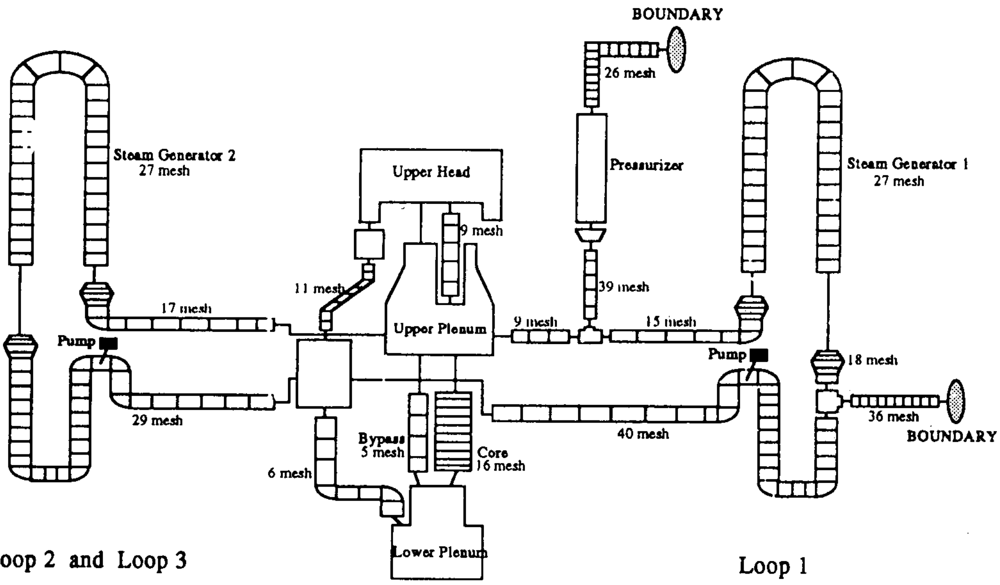

Fig. 1. CATHARE Nodalization for BETHSY Test 6.9c

the experiment is terminated. Major event chronologies are compared with the experimental data in Table 2. Noticed differences are found in the times which maximum pressure is reached and mixture level has its minimum value.

When the manway valves are opened, the mixture level in the hot leg reaches both the surge line and the inlet plenum of steam generator 1 immediately. The upper plenum pressure mostly depends on both the surge line Differential Pressure (DP) and the pressurizer DP. Figure 2 presents upper plenum pressure behaviors both in the simulation and in the exper-

Table 2. Chronology of Major Event

(unit : second)

Event	TEST 6.9c	
	Experiment	Calculation
Core power turned on, Manway open	0.0	0.0
Core power 140 kw	15.0	15.0
Maximum pressure	946 (0.125 MPa)	1815 (0.132 MPa)
Cladding temperature increase	4620	5110
Minimum Core level	5040	5960
Gravity injection (Tc = 523 K)	5660	5985
Mixture level reached hot leg	9017	9180
Test stop	9688	9500

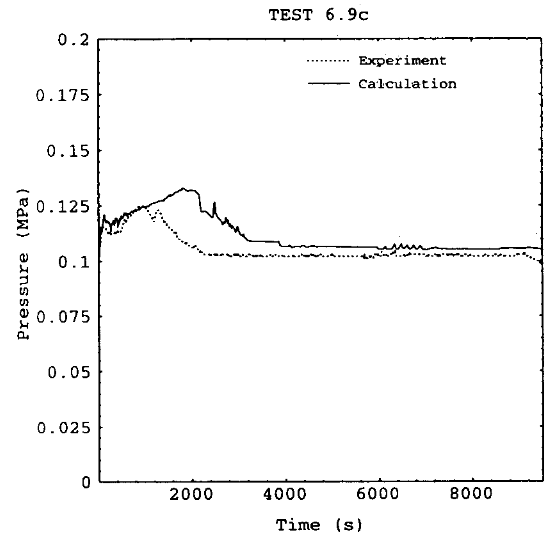

Fig. 2. Pressure at the Upper Plenum

iment. In this result, upper plenum is rapidly pressurized due to rapidly swelling of the coolant in the core with the beginning of transient. It gives to sharp increase of vapor release through the pressurizer manway (Fig. 6) and then goes down slowly with increasing of surge line DP. The pressurization also causes the vapor and liquid mixture to be expelled through steam generator manway (Fig. 7), resulting in momental drop of RCS pressure around 100 seconds. The liquid flow in the steam generator manway flow mostly comes from the crossover leg 1 and the steam flows pass through the hot leg and the steam generator 1 U-tubes.

The sum of both the pressurizer DP and the surge line DP affects on the RCS pressurization because vapor usually occupies the upper part of the system. When the sum of both DPs reaches a certain value, the steam flow penetrating the liquid in the pressurizer or the surge line becomes smaller due to the drag force exerting between two phases. Subsequent reduction of the steam velocity causes that the liquid in the pressurizer fall down to the surge line. Then the upper plenum pressure as shown in Fig. 2 increase due to rising the sum of both DPs. This phenomenon is repeated 3 times until around 2500 seconds which two phase level disappears in the hot leg. Thereafter system pressure sustains same value until gravity feed is injected. The interpretation is based on the fact that the time which the pressurizer DP drops coincides with the time of the surge line DP increase as illustrated in the Fig. 3 and 4. There are 3 peak pressure at 100, 1000, and 1300 seconds. The peak pressure in the upper plenum appears at that time which increased DPs, sum of both the pressurizer DP and the surge line DP, begin to decrease.

CATHARE predicts somewhat different behaviors in the pressurizer DP and the surge line DP from those of the experiment. The different behaviors are begun to appear from around 100 seconds which corresponds to the first minimum pressure in the upper plenum with termination of two phase discharge at the steam generator manway. The origin of misprediction is overestimation of liquid entrainment at the horizontal tee branch from the beginning of transient. Hot leg pressure increases due to the core swelling is overpredicted by 5 kPa in the calculation than in the experiment. The increased hot leg pressure results in faster steam velocity in the surge line by higher pressure difference between the hot leg and the pressurizer. This caused to calculate high interfacial

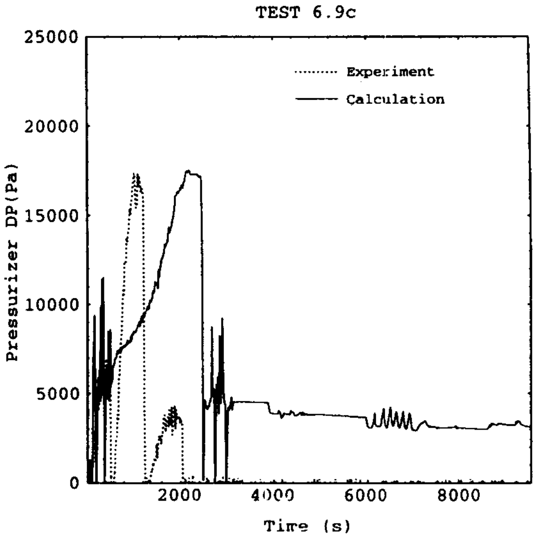

Fig. 3. DP at the Pressurizer

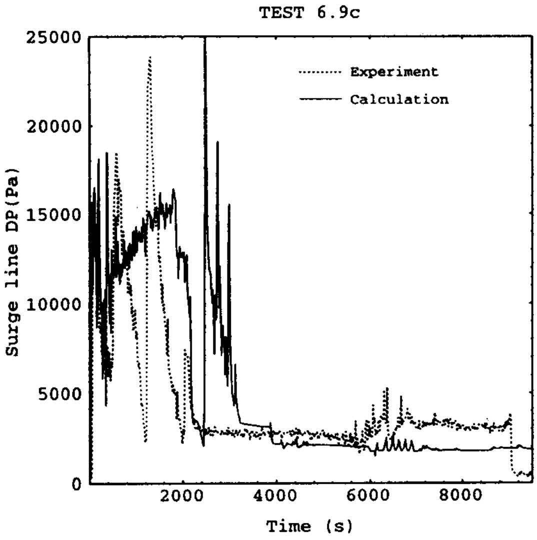

Fig. 4. DP at the Surge Line

drag force in the surge line because it is proportional to square of difference between steam velocity and liquid velocity. As this result, the surge line DP and the pressurizer DP in the calculation are appeared different behavior from those of the experiment. When the mixture level falls down below the hot legs, the pressurizer DP drops quickly in the experiment while some liquid is hold-up in the pressurizer until termination of the transient in the calculation because of high interfacial drag force in the surge line. Counter-Current Flow Limitation (CCFL) at the junction between the surge line and the pressurizer does not occur in the experiment but the code predicts the phenomenon with steam velocity of about 40m/s at the surge line.

As liquid is built up in the pressurizer, the upper head bypass flow suppresses the liquid in the vertical part of pump side crossover leg, moving the liquid in the vertical part of steam generator side crossover leg towards the steam generator manway. This behavior is represented in Fig. 5. The DP in the vertical part of pump side crossover leg drops dramatically from around 400 seconds, which is an evidence of downward liquid suppression. The liquid level in the pump side crossover leg 1 reaches a minimum value of 60 cm above the crossover leg bottom but loop seal clearing does not occurs. In contrast with the experiment, the code predicts the occurrence of loop seal clearing in the crossover leg 1 (Fig. 5). The loop seal clearing results in reduction of interfacial drag in the surge line because the steam velocity in the surge line decreases and the steam velocity increases toward the steam generator U-tubes. From Fig. 3 and 4, the calculated surge line DP drops earlier than the pressurizer DP around 2000 seconds, which means that reduced steam velocity is established due to reduction of interfacial drag in the surge line. The second sharply rising of surge line DP in the simulation roughly from 2500 through 3200 seconds results from the short time reversal flow from the pressurizer to the surge line. The overprediction of upper plenum pressure which is depend on both the pressurizer DP and the surge line DP results in higher the loop 1 DP. It is caused by the loop seal clearing.

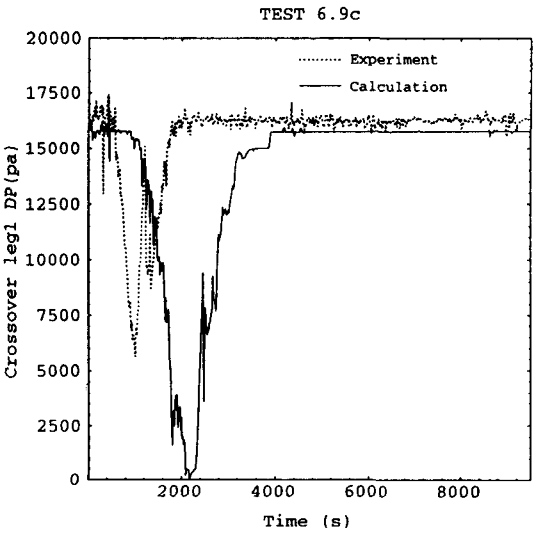

Fig. 5. DP at the Pump Side Crossover Leg 1

Figure 6 and 7 shows the pressurizer and the steam generator outlet plenum manway flow rate, respectively. As previously mentioned, filling and clearing in the surge line is repeated as long as two phase level exists in the hot leg 1. As RCS pressure increases, liquid is pushed from cold leg 2 and 3 to steam generator manway through crossover leg 1. Subsequently, two phase mixture discharge appears through the steam generator manway in contrast with single phase steam discharge through the pressurizer manway. This phenomenon is predicted by the CATHARE2 code but the code overestimates the pressurizer manway flow when two phase level exists on the hot leg 1 coming from overprediction of pressurizer DP. Although liquid holdup in the pressurizer may be increased, the pressurizer manway flow rate sustains with almost the same level as seen from Fig. 6 because upper part of the pressurizer is always occupied by steam due to the volume model characteristics in the CATHARE2. As shown in Fig. 6 and 8, the excessive break flow at the pressurizer manway results from overprediction of pressurizer DP except beginning of transient. In contrast, the steam gener-

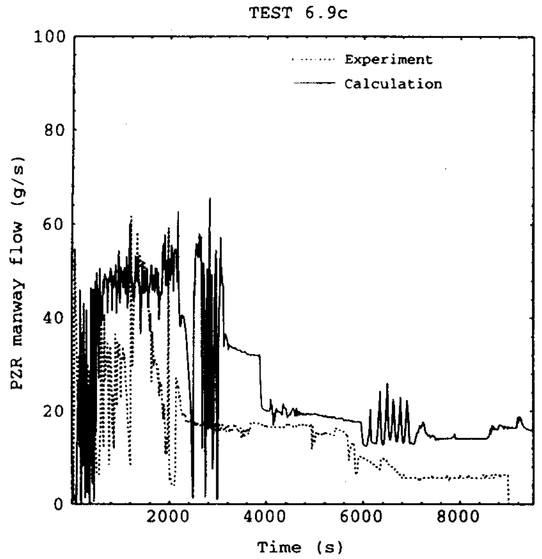

Fig. 6. Flowrate at the Pressurizer Manway

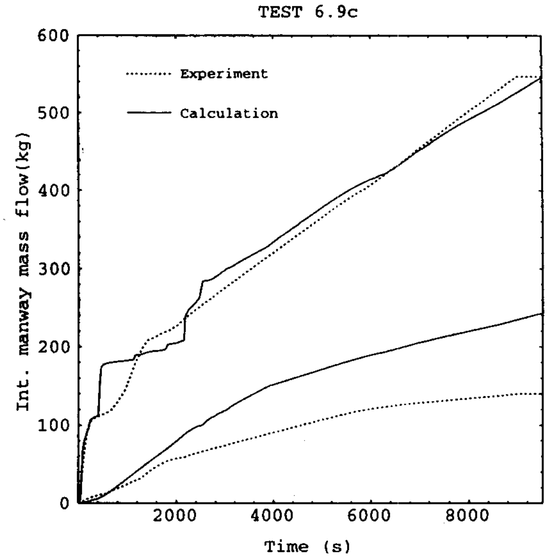

Fig. 8. Integrated Manway Flowrate

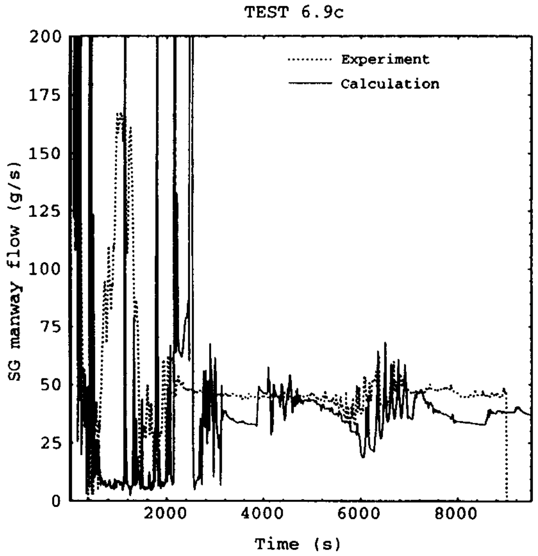

Fig. 7. Flowrate at the Steam Generator Manway

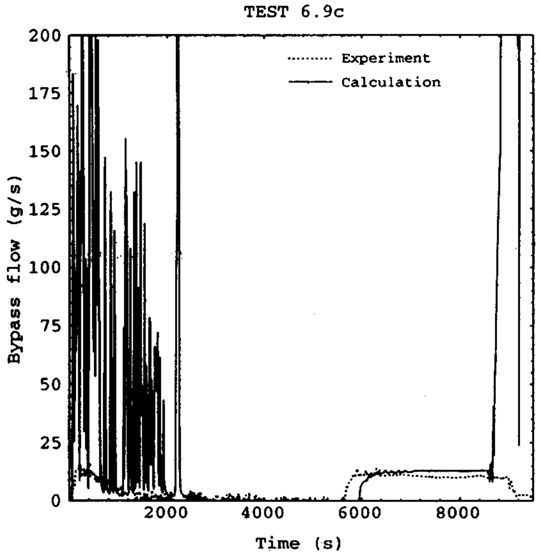

Fig. 9. Flowrate at the Upper Head Bypass

ator manway flow behaves so complicatedly, depending on the RCS pressure, upper head to downcomer bypass, the surge line and the pressurizer behaviors, loop seal clearing, etc. General prediction for the flow through the steam generator manway in Fig. 7 and 8 by the code is acceptable, however, larger two phase mixture is obtained in the calculation than that in the experiment. The reason could be that vapor which moves to cold leg through upper head to downcomer bypass path is overestimated, meanwhile, the pressurizer manway flowrate is slightly reduced till 600 seconds. This description is based on the behaviors to 2500 seconds. Thereafter only vapor discharges through both manways.

The calculated upper plenum pressure increases without filling and clearing in the surge line until loop seal clearing is occurred in the crossover leg 1. This is main factor affecting on the higher upper plenum pressure prediction. Also high upper plenum pressure is caused to delay liquid hold-up in the steam generator 1 U-tubes because void fraction is lower than that in the experiment. As stated above, the maximum pressure is overestimated by 8 kPa and the pressure rises rather slowly. The discrepancy of the timing in the calculation apparently comes from liquid entrainment in the tee junction between the surge line and the hot leg under horizontally stratified flow in the hot leg l as well as unrealistic modelling of guide tube. The overprediction of the bypass flow may give rise to reduction of manway flow moving towards both the pressurizer and steam generator U-tubes. It also contributes to slowing down of liquid hold-up rates in the surge line as well as the upside U-tubes region. Figure 9 obviously exhibits the overestimation of this bypass flow. Bypass flow will be discussed later.

Following the initiation of the transient, the coolant temperature in the core begins to rise quickly, and the steam generated in the core discharges through the manway vents. Figure 10 shows the DP in the core. In the experiment, the DP is almost same order until the active core is uncovered. As the coolant inventory is reduced below certain amount, the core begins to be uncovered (Fig. 11) and the fuel cladding gets heated up rapidly (Fig. 12). As the cladding temperature increases, gravity feed is supplied in the cold leg 3 by the experiment condition.

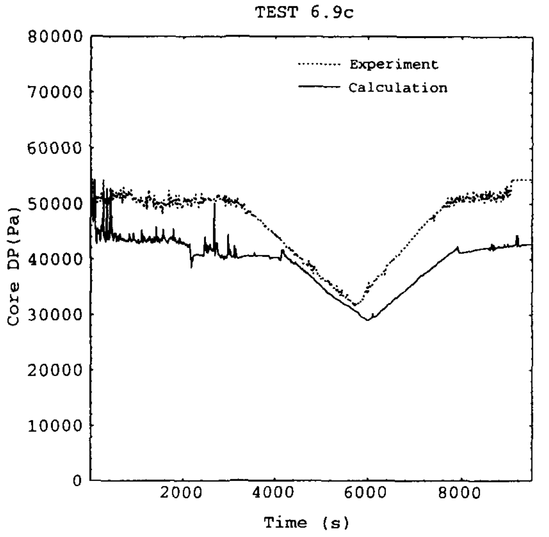

Fig. 10. DP at the Core

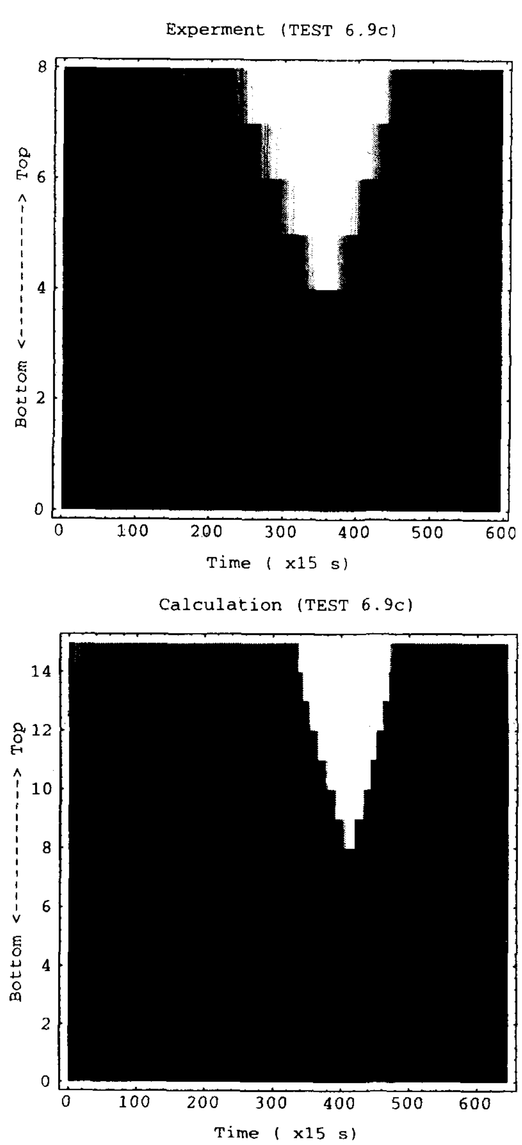

Fig. 11. Void Distribution in the Core

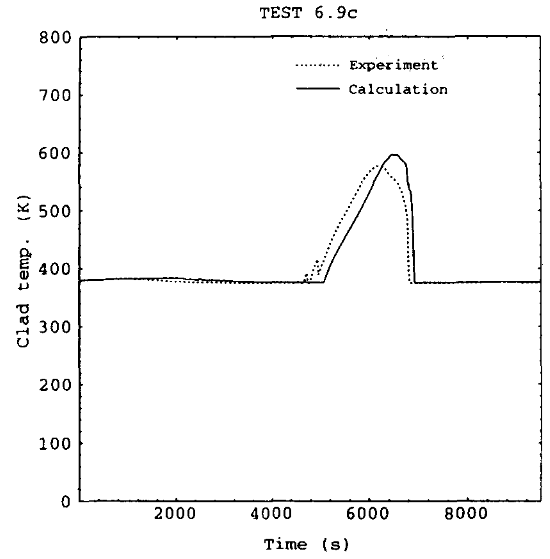

Fig. 12. Peak Cladding Temperature

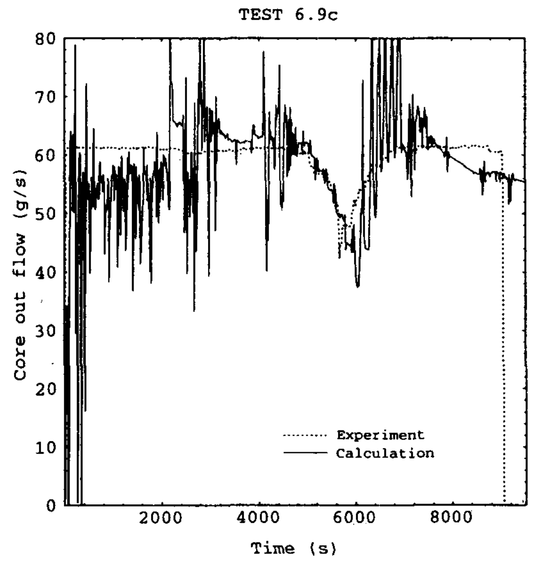

Fig. 13. Vapor Flowrate at the Core Outlet

The core is refilled with liquid afterward. The overall transient represented by CATHARE is similar with the experiment, but the core DP is definitely underestimated while the timing of the core uncovery is delayed. Reasons are due to multi-dimensional effects like cross flow in the core that are not captured in the calculations because CATHARE code is one-dimensional code and overprediction of interfacial drag force in the core. CATHARE2 models the core channel with two parallel pipes of which one is active core and the other is core bypass. The core bypass flowrate could also affect on the core void distribution. The larger bypass flow downward from the top of the active core increases liquid temperature at the core inlet. Thus void distribution will be higher even though the downcomer flowrate might be preserved in the same value (Fig. 11). Also, interfacial drag model for bundle type geometry is overpredicted by CATHARE2 code. The more steam stays in the core, the less core DP should be expected. But this effect does not seem to be significant. Though interfacial drag force reduces half of the original value, the core DP improves only 1.2 kPa which is correspond 2.6% of basecase core DP. As result of those effects, the calculated core DP is less than that of the experiment by 7 kPa for the experiment until the core uncovery.

The continuous core inventory reduction leads to the core uncovery and it causes the cladding temperature excursion. The peak cladding temperature is shown in Fig. 12. As shown in Fig. 11 concerned with the core void distribution, the core uncovery is observed around 4620 seconds in the experiment but the code predicts its occurrence about 5110 seconds. Although vapor generation is predicted reasonably in Fig. 13, CATHARE2 overpredicts the void distribution in the core. This is due to combined effects of both limitation of one-dimensional model and overprediction of interfacial friction. CATHARE2 is reported to predict void distribution adequately in high pressure [12], but it seems to overpredict in low pressure as stated above. The peak temperature is 573 K in the experiment and the code estimates 590 K which is overestimated 17 K because the core void distribution is overpredicted as shown in Fig. 11 as well as gravity injection flow rate is relatively smaller than the experiment. Once the core inventory recovers by the gravity feed injection, the cladding temperature drops. Gravity injection is sufficient to cool the core in the experiment as well as in the calculation because relatively lower cold leg pressure results in large injection flow [11, 14]. Accordingly, there is no necessity of an additional forced injection. Gravity injection causes repartition of manways flow and bypass flow. The pressurizer manway flow slightly decrease and the steam generator manway flow increases due to increase of bypass flow induced by condensation in the cold leg. The calculations also represent those behaviors adequately (Fig. 6 and 7).

One of the most sensitive parameter in the test is upper head to downcomer bypass flow because that affects on the manways flow and the system pressure. The increased loop DP makes more steam drawn to cold legs from upper plenum through the guide tube and the dome. Considerable amount of steam generated in the core would flow into the bypass rather than flowing toward the pressurizer manway and the steam generator U-tubes. Most of the bypassed steam is condensed in the upper part of the downcomer where liquid still remains subcooled. The maximum steam flowrate in the upper head to downcomer bypass reaches 14 g/s in the experiment. This corresponds to 22 % of the core outlet steam flowrate. When gravity feed injection is actuated into the primary system, the reduced bypass flowrate increases again by 18 % of the core outlet steam flowrate in the experiment (Fig. 9). During early parts of transient, only steam passes through upper head to downcomer bypass in the experiment but two phase flows in the calculation. As shown in Fig. 14, the calculated DP along the guide tube is much higher than that of the experiment. This is one of the weak point in this analysis because it can not be properly modeled with one dimensional axial module. It is important to choose location of guide tube upstream junction since bypass flowrate will be improved as the upstream junction location is moved upward.

Finally, Table 3 summarizes computation statistics for the experiment. As shown in Table 3, heavy oscillation period when liquid is entrained in the surge line consumes long CPU times. CPU time took for the test is over 34 hours for real time of 2.5 hours by CRAY-YMP machine.

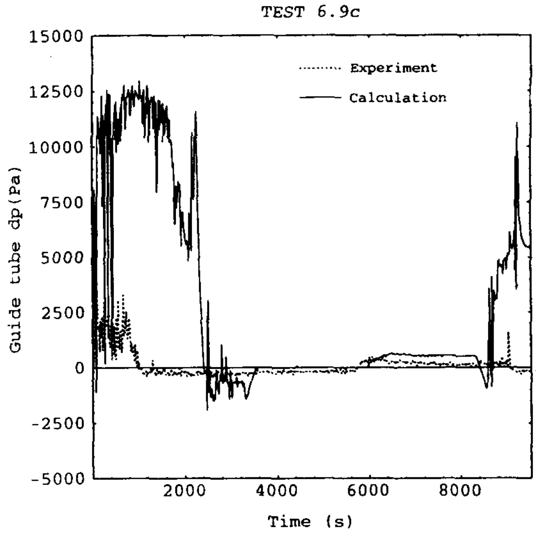

Fig. 14. DP at the Guide Tube

Table 3. Comparison of Computation Times

(unit : second)

	Test 6.9c
No. of Volume	419
Experimental time (1)	2000
CPU time (1)	8.302×10^4
Experimental time (2)	9500
CPU time (2)	1.254×10^5
Max. time step[a]	1.0
Min. time step	8.64×10^{-6}
No. of time step	107954
Average time step[b]	0.088
CPU time / Exp. time	13.2
Grind time[c]	2.77×10^{-3}

a : user input

b : (Experimental time)/(No. of time step)

c : (CPU time)/(No. of Volumes)/(No. of time step)

5. Conclusions

Under loss of RHRS during a mid-loop operation, the system responses according to two manway paths are investigated by analyzing the experiments with the CATHARE2 code. The loss of RHRS is simulated for 9500 seconds with a constant power 140 kw in the experiment.

In order to mitigate loss of RHRS accident, the pressurizer manway and the steam generator outlet plenum manway open can manage the core uncovery by only gravity feed injection because of relatively lower cold leg pressure.

The peak pressure in the upper plenum is 21 kPa higher than the initial pressure in the experiment but the code predicts higher value by 28 kPa because the pressurizer and the surge line DP are overestimated. The timing of the core uncovery, i.e. the maximum available time which an operator takes action to recover, is 4620 seconds in the experiment. The result of the CATHARE2 calculation is around 5110 seconds. The calculated results which is delayed the core uncovery time than that of the experiment is due to discrepancy in the core void distribution. CATHARE2 overpredicts the core void distribution primarily due to multi-dimensional effects that can not capture in the one dimensional code CATHARE and overprediction of interfacial drag in the core. The peak cladding temperature is 573 K in the experiment but the code predicts the value of 590 K. The main reason comes from the misprediction of the core void distribution as well as small gravity injection flow rate. The calculated guide tube flowrate which is a sensitive parameter to the system behavior is larger than that of the experiment. This is regarded as one of the weak point in this analysis because it can not be properly modeled with one dimensional axial module. From the present analysis, it is found that the branch model of CATHARE2 which exert an influence on the calculation of the liquid entrainment and hold-up should be qualified for low pressure.

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