Journal of the Korean Nuclear Society
Volume 21, Number 4, December, 1989

Assessment of RELAP5/MOD2 with LOFT L2-5 LBLOCA Test

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(Received May 31, 1989)

LOFT L2-5 대형 냉각제상실사고 모사실험에 대한 RELAP5/ MOD2 코드 평가

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(1989. 5. 31 접수)

Abstract

An improved version of RELAP5/MOD2 Cycle 36.04 code is assessed for LOFT LBLOCA Test L2-5. Minor modifications to the original version have been done to avoid reflood related errors. Based on the modified version, one base case and two cases for sensitivity study on downcomer and core channel modelling are calculated. The calculation results are compared with the experimental data for primary system pressure, break mass flow rate and cladding temperature at hot spot. According to the comparison, it is found that the hydraulic system behaviors are well predicted, excessive core cooling exist in blowdown phase for a single core channel and a combined downcomer case, and a better result can be obtained for a two core channel case.

요 약

LOFT L2-5 대형 냉각재상실사고 모사실험에 대해 RELAP5/MOD2/Cycle 36.04로부터 개선된 코드를 이용, 코드평가를 수행하였다. 강수관(Downcomer)모델 및 노심유로모델에 따른 코드 민감도분석을 위해 보충계산을 수행하였다. 계산결과는 1차계통의 압력, 파단부를 통과하는 질량유량, 노심 고온부의 피복재 온도등에 대해서 실험결과와 비교 분석되었다. 분석결과 RELAP5/MOD2 계산에 의해 1차계통의 수력학적 거동은 잘 묘사될 수 있으며, 단일 노심유로 모델을 이용한 계산에서는 사고발생이후 감압기간동안 노심이 과대 냉각되는 현상이 발견되었다. 노심의 고온유로에서의 수력학적 거동을 잘 묘사할 수 있는 이중 노심유로모델계산을 이용하여 이 현상을 극복하고 실험치에 근사하는 결과를 얻을 수 있음을 알 수 있었다.

1. Introduction

Since RELAP5/MOD2, thermo-hydraulic code, was developed by Idaho National Engineering Laboratory (INEL) (1), a number of calculations by using this code have been carried out through International Code Assessment and Application Program (ICAP) to figure out the code capability and deficiency (2). Key points found through these experiences are mainly on the capability of code to describe a postulated large break loss of coolant accident (LBLOCA), which is a beginning point of RELAP5/MOD3 development (2).

In this study an assessment was performed for an improved version of RELAP5/MOD2, which was developed for LBLOCA analysis, based on Cycle 36.04.

The primary objective of this study is to assess the capability of the improved version to describe LBLOCA using LOFT L2-5 Test. In addition, sensitivity studies have been carried out to find out the effects of the downcommer and core channel modelling on the core thermal response.

2. Facility and Test Description

The Loss of Fluid Test(LOFT) Facility is a 50 MWt nuclear PWR with instrumentations to measure and provide data on the thermal hydraulic conditions throughout the system.

Experiment L2-5 was planned to simulate a 200% double ended LBLOCA in the cold leg of 4 loops commercial PWR (3). Also an accident was initiated from conditions representative of a PWR operating at normal power with coincident loss of site power, resulting in a typical pump coastdown which was mainly to prevent the occurrence of the early return to nucleate boiling

Table 1. L2-5 LBLOCA Initial Values from Steady State Calculation

Parameter	Measured	Calculated
• Primary Coolant System		
Mass flow rate*, kg/s	192.4	192.4
Hot leg pressure*, MPa	14.94	14.918
Core delta T, K	33.1	33.03
Cold leg temperature*, K	556.6	556.49
• Reactor Vessel		
Power level, MW	36.0	35.69
Maximum Linear heat generation rate, kW/m	40.1	39.8
• Pressurizer		
Liquid temperature, K	615	614.7
Pressure, MPa	14.94	14.94
Liquid level*, m	1.14	1.1389
• Steam Generator secondary side		
Saturation temperature, K	547.1	546.22
Pressure, MPa	5.85	5.78
Mass flow rate, kg/s	19.1	18.7
Level*, m	3.1293	3.12

Note *: Setpoint in steady state controllers in the core (i.e. rewet). Table 1 shows the comparison of the measured initial conditions of experiment L2-5 with the calculated initial conditions by RELAP5/MOD2. And the measured sequence of events are presented in Table 2 with the simulated results.

3. Descriptions on Code and Calculation Method

An improved version of RELAP5/MOD2 Cycle 36.04, frozen by USNRC, are used in this analysis. The modified items and their reasons are listed in Table 3.

For a simulation of LOFT L2-5 Test, original input deck was developed by INEL (4). The nodalization schemes in this analysis are bascially same as the original one, which is shown in Figure 1. From the experience of preliminary calcualtion using original input prior to this study, the boundary condition of containment pressure, 0.1 MPa, was found to prevent the core from quenching in 100 sec, and to be fixed consistentely with the experiment. Some items including containment pressure, has been modified for base case calculation. Changed items and their reasons are listed in Table 4, and compared with the original one.

Two cases of calculation are executed for sensitivity study based on base case calculation as shown in Table 4. The purposes of sensitivity study are to find out the sensitivity of the thermohydraulic behavior with core channel models and downcommer models. Figure 2. shows the comparison of core and downcommer models used in this sensitivity study.

Table 2. Sequence of Events for L2-5 LBLOCA Experiment

Event	Measured,sec /Uncertainty	Calculated,sec
Experimetn initiated	0	0.
End of Subcooled Blowdown	0.043/0.01	0.01
Reactor Scrammed	0.28/0.2	0.015
Clad Temperature deviated from saturation	0.91/0.2	3.4
Primary Pump Coastdown initiated*	0.94/0.5	0.94
End of Subcooled Break flow (cold leg)	3.4/0.5	2.55
Top-down Quench initiated	12.1/1.0	**
Pressurizer Empty	16.3/2.0	13.6
Accumulator Injection	17.3/0.7	15.0
End of Top-down Quench	22.7/1.0	**
HPIS initiated*	24.0	24.0
Peak Clad Temperature reached	28.5/0.5	47.0
Lower Plenum Refill	31.2/1.0	30.9
LPIS initiated*	37.0/0.5	37.0
Accumulator Empty	49.4/1.5	33.0
Core Reflood completed	55.3/1.5	63.0
Core Cladding Quenched	65.0/2.0	67.0

Note *: specified by input, **: not available

Table 3. Improved items in the code from RELAP5/MOD2 Cycle 36.04

Subroutine	Description	Reason	Reference
RACCUM	• Correction of indexing	Fix index error	KWU
IHTCMP	• Correction of indexing	Fix index error for gap pressure calc.	
QFHTRC	• Fix radiation heat transfer	To avoid a limiting case in Radiation	
	• Modification of HTV1	Fix negative heat transfer coefficient	STUDSVIK
IRFLHT	• Modification of geometric indicator	To work heat slab for reflood in restart	STUDSVIK

4. Results and Discussions

4.1 Steady State Calculation

The purpose of steady state calculation is to get initial values for postulated LBLOCA simulation. To accelerate the steady state calculation seven steady state controllers are used ;2 RCP speed controllers, 1 pressurizer spray valve area control, 1 PZR heater power controller, 1 PZR level controller, 1 MSIV area controller and 1 Feedwater flow rate controller.

The results of steady state calculation are listed in Tabel 1. According to this table, it is shown that the satisfactory steady state initialization was achieved especially in a viewpoint of setpoint values. Slightely low value in S/G secondary pressure can be considered as a result of geometric difference from the real facility.

Table 4. Base Case Calculation Input Model Features

items	Base-case	Original Deck	Reason
PZR Heater	power table set to zero in transient deck	Heat structure for heaters deleted in transient deck	To avoid Reflood related error
Reflood option	Pressure at upper plenum<1.0 MPa	Set to not turn	To initiate a reflood option
Heat slab # in core	Central fuel: 0021 Peripheral : 0011	Central fuel: 2310 Peripheral : 2320	To aviod reflood related error
Containment pressure	Time dependent data: 0.1-0.3 MPa	Constant value: 0.1 MPa	To describe L2-5 test accurately
Accumulator empty level	0.93 m	1.2 m	
Power Table	L2-5 Posttest data + ANS 79 Decay data	L2-5 Possttest data only	

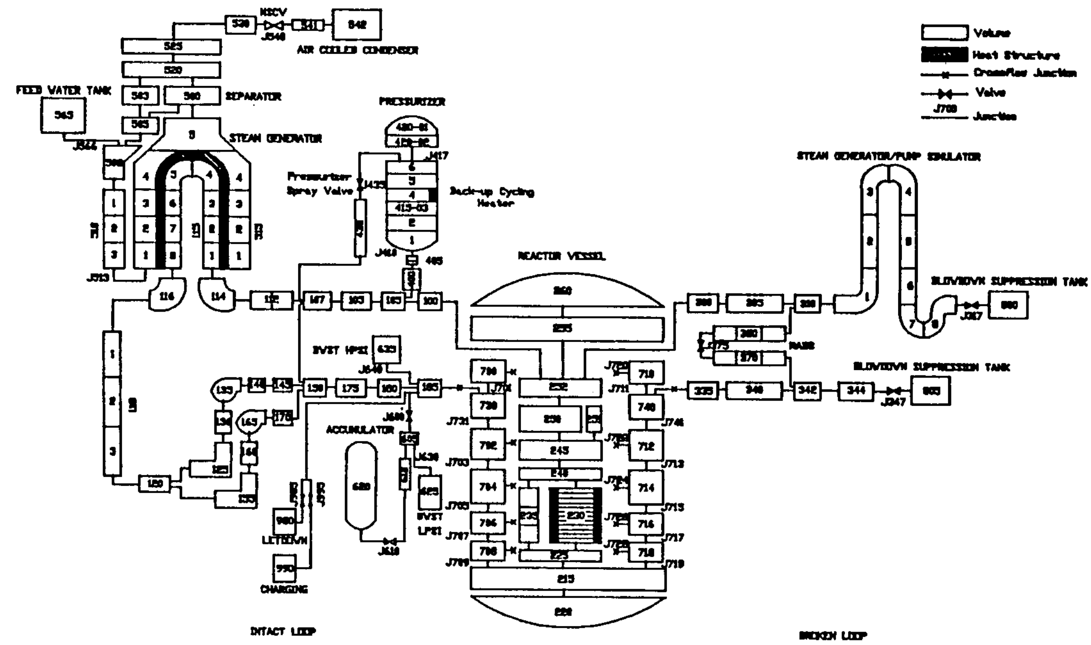

Fig. 1. Nodalization diagram for base case calculation of LOFT L2-5 test

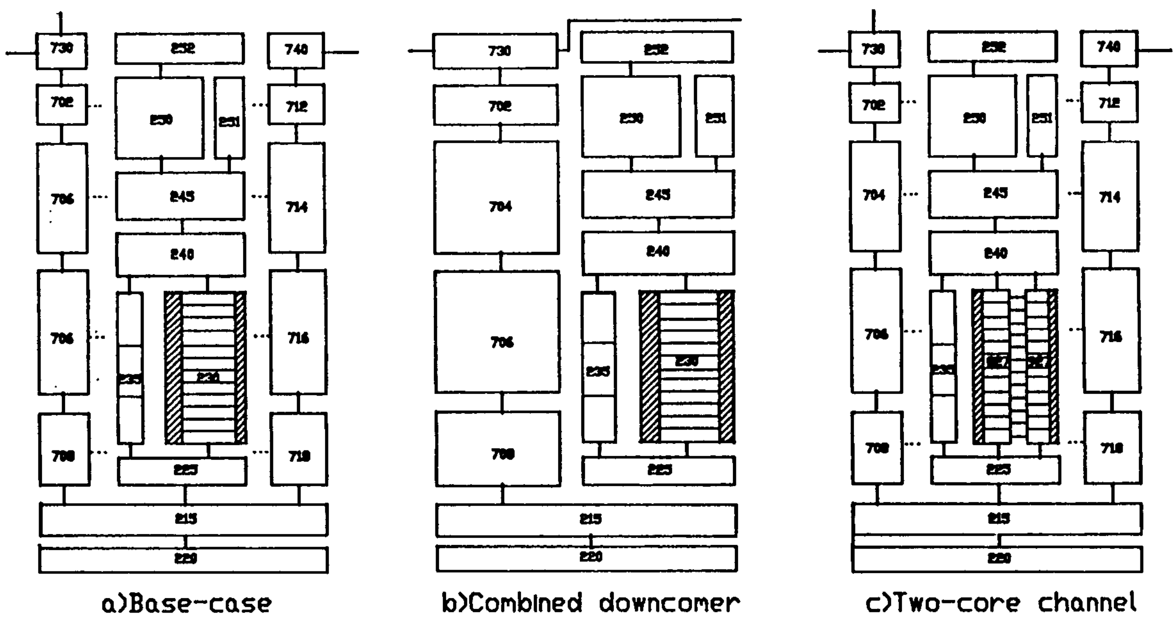

Fig. 2. Comparison of nodalization of reactor vessel

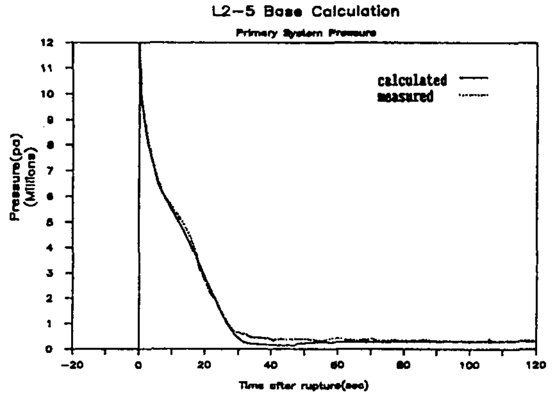

Fig. 3. Comparison of primary system pressure between base-case calculation and experiment

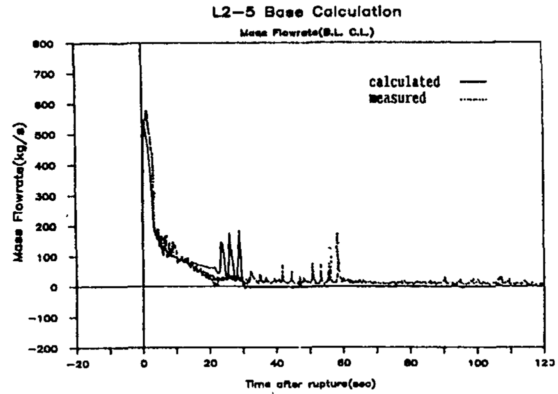

Fig. 4. Comparison of mass flow rate at broken loop cold leg between base-case calculation and experiment

4.2 Transient Calculation

4.2.1 Base-case Calculation

Based on steady state initialization results, L2-5 LBLOCA transient calculation was executed with a base-case input deck. The calculated sequence of events are compared with the measured data in Table 2.

Primary system pressure was plotted in Figure 3 with experimental data. The calculated depressurization behavior is well agreed to the measured up to 25 sec. (Blowdown phase). After that time, the calculated one is a little lower than the measured, however, similar trend is found throughout the whole transient.

Figure 4 shows a comparison of the calculated mass flow rate at broken loop cold leg with the measured. Sudden peaks are observed at 20-30 sec, in calculated flow rate, which was considered to be caused by code deficiency of the interfacial drag model. In that period the accumulator water

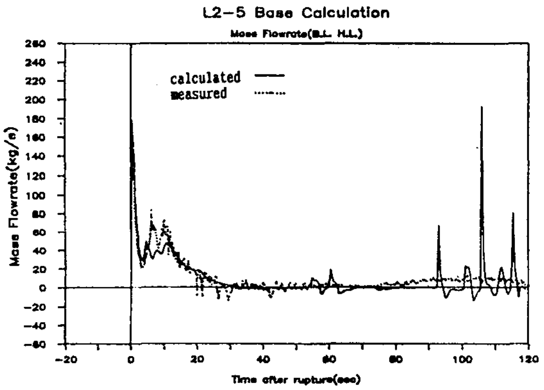

Fig. 5. Comparison of mass flow rate at broken loop hot leg between base-case and experiment

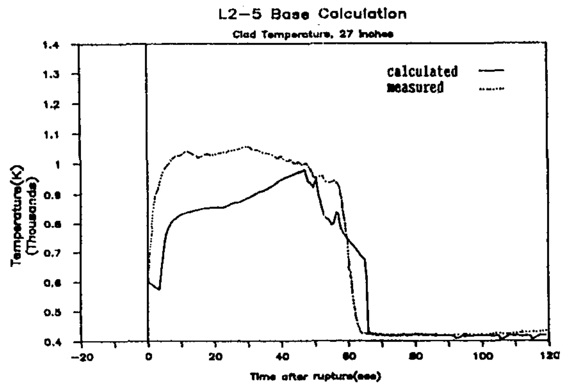

Fig. 6. Comparison of cladding temperature at hot spot region, 27 inches from bottom of the core between base-case calculation and experiment

was initiated to inject (Table 2) and discharged to break node by the excessive highly-estimated interfacial drag without entering the core during the early period of injection. The calculated mass flow rate at hot leg was well agreed to the measured data in the whole period of transient except the later peaks, which cannot be understood in current status (Figure 5).

Figure 6 shows a comparison of cladding temperature at hot spot region, 27 inches from the bottom of the fuel. It is shown that the calculated PCT (991.9 K) is lower than the measured PCT (1030 K) and that the whole thermal behavior is slower than the experiment; i.e., later deviation from saturation and later quenching. It is also found that the core was not heated up in the blowdown phase owing to the excessive core cooling.

4.2.2 Sensitivity Study

As shown in Table 5, two additional calculations were performed for the sensitivity study, by which the effect of the downcommer modelling and core channel modelling on the core thermal response can be found.

Figure 7 shows a comparison of cladding temperature at hot spot (27 inches) for 3 cases, that is base-case, combined downcomer and two core channel. It is shown that the result of two core channel case is closer to the experiment than those of base-case and combined downcomer case in blowdown phase.

According to Figure 7, PCT is occured at reflood phase in calculation but at blowdown phase in experiment. This difference can be considered as deficiency of reflood heat transfer correlation used in current code.

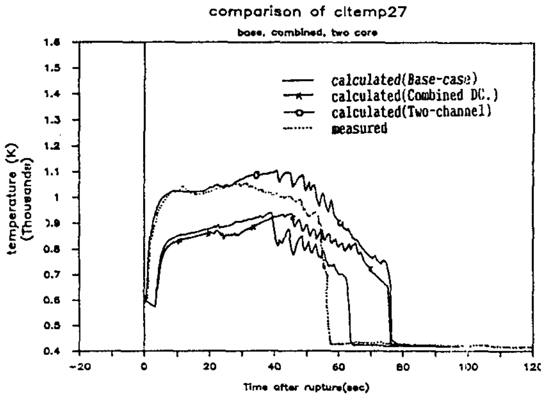

Fig. 7. Comparison of caldding temperature at hot spot (27 inches) for 3 cases of calculation

Figure 8 shows another comparison of cladding temperature at 39 inches hot spot. There are no top-down quenching (rewet) in 3 cases of calculation, which was also observed in experiment. It imght be due to incorrect rewet criteria and deficiency of interfacial drag.

Table 5. L2-5 LBLOCA Calculation Matrix

Case	Core channel model	Downcomer model
Base-case	Single channel (12 volumes)	Splitted
Case A	Single channel (12 volumes)	Combined
Case B	Two channel (12 volums/ch)	Splitted

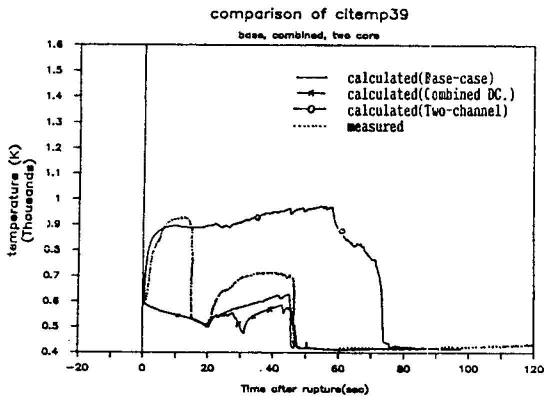

Fig. 8. Comparison of cladding temperature at hot spot (39 inches) for 3 cases of calculation

5. Conclusions

An improved version of RELAP5/MOD2 cycle 36.04 was assessed for LOFT L2-5 LBLOCA Test.

Base case and other 2 cases were calculated and compared with experiment data, and following conclusions are obtained.

1) Hydraulic behavior was well predicted for L2-5 test by the improved version of RELAP5/MOD2 Cycle 36.04.
2) An excessive core cooling was found in blowdown phase by using single core channel model. Two core channel model is effective to avoid an excessive core cooling. The effect of combined downcomer model is negligible on the core thermal response, especially on PCT.
3) The currently implemented models of interfacial drag, rewet criteria and reflood heat transfer need to be improved.

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