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Preliminary Analysis of LOFT LP-FW-1 Test using SPACE code

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1. Introduction

After the Fukushima accident, a severe accident is the biggest issue in a nuclear safety. As a part of that, worldwide regulation bodies have legislated design extension conditions (DEC) to mitigate the reactor core damage including severe accident and to restrict an exposure of radioactive materials [1-2]. Therefore, it is important to evaluate initiating events for the DEC and to develop safety analysis methodologies of those events. In this study, the LOFT LP-FW-1 test is analyzed using SPACE code. The LOFT LP-FW-1 test simulated a total loss of feed water (TLOFW) events, which is one of the initiating events categorized in the DEC [3]. Thus, this result can be a basis of methodology for TLOFW analysis using SPACE code.

2. LOFT LP-FW-1 Test

The LOFT facility simulated a typical, commercial 4-loop PWR reactor core, primary coolant system, and ECCS. Fig.1 shows the schematic of the LOFT facility. The LOFT reactor power is 50 MWt. It has five major systems: primary coolant, reactor system, blowdown suppression system, emergency core cooling system, secondary coolant system. The primary coolant system has an intact loop and a broken loop, which simulates a pipe break.

The LP-FW-1 test is conducted as a part of OECD LOFT project [4]. The LP-FW-1 is initiated with failure of main feed-water supply and an auxiliary feed-water is not available, simultaneously. Initially pressure is increased due to a feed-water pump trip. Then, the reactor scrammed, the PORV in the pressurizer is latch opened and the MSCV is started to close by the primary set pressure of 15.73 MPa.

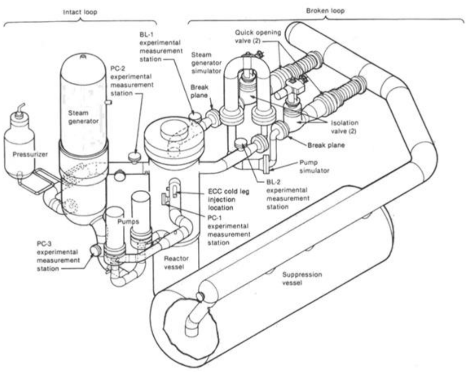

Fig. 1 LOFT facility schematics

Table I: LOFT LP-FW-1 Scenario

Main Events	**Time [sec]**
Main feed-water pump tripped	0.0
Pressurizer spray initiated	33.2
Reactor tripped on high pressure	48.8
MSCV starts to shut	48.8
PORV latched open	50.8
MSCV fully shut	61.0
SG liquid level reached bottom	85.0
PC pump coastdown	219.0
HPIS initiated	221.6
PC pump coastdown completed	235.5
First void formation in primary	245.0
Pressurizer liquid level reached top	333.2
PORV transition from steam to two-phase	339.0
HPIS flow exceeds PORV discharge flow	2370.0
Experiment terminated	6820.0

After PORV opened, the system pressure is continuously reduced. When the primary pressure reached to 8.76 MPa, the primary pumps are tripped and the HPIS is initiated. Thus, the system pressure and temperature monotonically decreased by a feed and bleed operation. Table I shows scenario of the LOFT LP-FW-1 [5].

3. SPACE Analysis Results

3.1 Modeling of LOFT LP-FW-1

Fig. 2 shows SPACE code nodalization for the LOFT LP-FW-1 test. This modeling is based on the LOFT L9-1/L3-3 input [6]. Major components including cold-leg, hot-leg, pressurizer, steam generator are modeled. The pressurizer is vertically connected with a surge-line pipe from the hot-leg in the intact loop. Especially, the PORV can be a key component, since its discharge flow will govern a transient behavior. Thus, a PORV relief

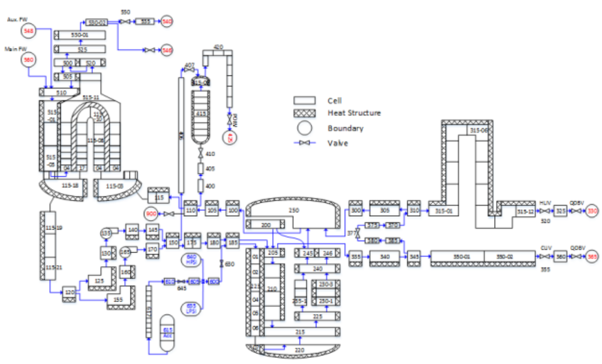

Fig. 2 LOFT LP-FW-1 Nodalization for SPACE code

Table II: LOFT LP-FW-1 Steady-state Results

Part	Parameters	Measured	SPACE
Primary	Power [MWt]	49.2	49.2
	Flow [kg/s]	346.13	346.14
	HL temperature [K]	581.3	580.85
	CL Temperature [K]	554.3	554.47
	HL Pressure [MPa]	14.8	14.83
SG	Water Level [m]	2.87	2.87
	Water temperature [K]	538.5	540.77
	Pressure [MPa]	5.3	5.3
	Feed flow [kg/s]	26.36	25.85
Pressurizer	Temperature [K]	615.5	614.37
	Pressure [MPa]	14.83	14.83
	Water Level [m]	0.96	0.96

line is additionally modeled based on available design data [7]. The U-tube type steam generator is modeled with heat structures. The HPSI is connected to the cold-leg in the intact loop. The reactor vessel is modeled with a downcomer and filler. The core is modeled with an active core including fuel assemblies and a bypass region. A broken loop is also modeled. However, in the LP-FW-1 test, it has no important role. The system heat losses are modeled based on the reference input [6].

3.2 Steady-State Results

The heater power in the pressurizer is adjusted to compensate its heat loss. All major parameters are well calculated for steady-state conditions. Table II shows steady-state results for the LP-FW-1 test.

3.3 Pre-Analysis Results (BASE-A)

Fig. 3 shows the intact loop hot-leg (HL) pressure during the short-term transient. After the trip of the feed-water pump, the primary pressure increased due to loss of heat removal capability. As shown in Table I, when the PORV is opened, the primary pressure is suddenly reduced. Then, the primary pump is tripped and the HPSI is initiated when the HL pressure reached the set pressure. The pre-analysis result shows that the pressure reduction rate is slightly under-estimated. Thus, the time of the pump trip and the HPSI initiation is delayed. Fig.4 shows the HL pressure during the

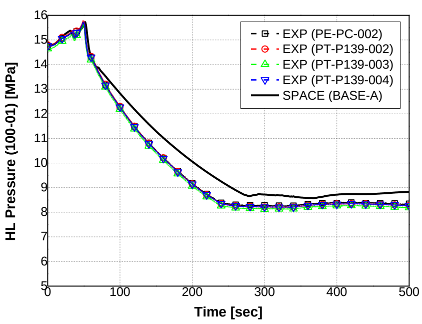

Fig. 3 Intact loop hot-leg pressure during short-term transient.

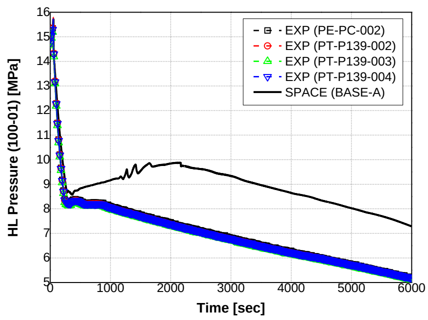

Fig. 4 Intact loop Hot-leg Pressure during long-term transient.

long-term transient. During the feed and bleed operation, experimental results shows monotonic reduction of the pressure. However, the analysis result is over-predicted during a long-term transient.

4. Sensitivity Analysis

4.1 Sensitivity Analysis Results

Sensitivity tests are conducted to understand the effect of the selected sensitivity parameters and to propose input parameters for the better prediction. The heat losses are modeled with heat transfer coefficients for three different regions of the primary system, steam generator, and pressurizer. These heat losses are considered as the sensitivity parameter. Dominant heat loss is observed in the primary system including the reactor vessel, hot-leg and cold-leg piping as shown in Fig. 5. Croxfod reported that a decay heat is over-predicted by 4% [5]. Therefore, the decay heat level is selected as a sensitivity parameter and its results are similar to that of the heat loss. The coefficients (DCs) for vapor and two-phase are selected as sensitivity test parameters. In the BASE-A case, all the DCs are 1.0. Fig. 6 shows the effect of the vapor DC on the primary pressure. When the vapor DC is increased, the pressure reduction rate is increased. In this case, the vapor DC of 1.2 indicates the best prediction. In addition, the time for the HPSI activation is corrected due to the better prediction of the HL pressure as shown in Fig. 7.

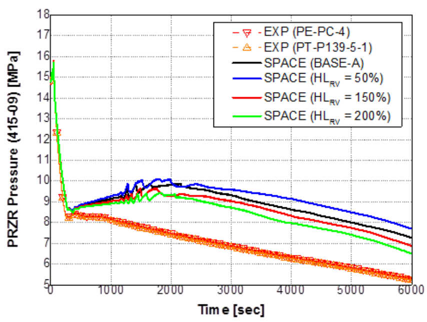

Fig. 5 Primary system heat loss effect on the pressurizer pressure.

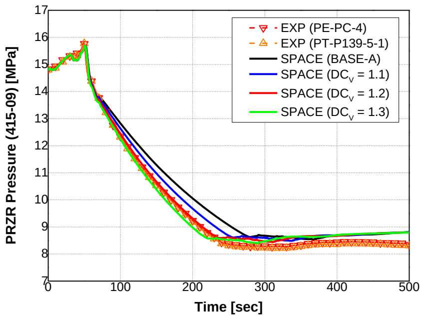

Fig. 6 Vapor discharge coefficient effect on the pressurizer pressure.

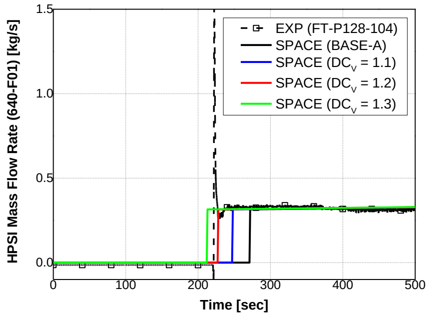

Fig. 7 Vapor discharge coefficient effect on the time of HPSI activation.

Fig.8 shows the two-phase DC effect on the PORV discharge flow rate. The experimental data is largely scattered. As the two-phase DC decreased, the PORV two-phase flow rate is reduced. Fig. 9 shows the cold-leg temperatures. The temperature has a sudden drop and fluctuation due to a reversed flow. Moreover, this trend is also observed in the experimental data after 4000 sec. When the two-phase DC is 0.7, the reversed flow is disappeared and temperature decreased without any fluctuation.

The flow regime in the hot-leg pipe during the transient is a stratified flow. Moreover, the pressurizer surge-line is vertically connected with the hot-leg as shown in Fig.1 and Fig.2. Thus, off-take phenomena can be influential. The off-take model is not considered in the BASE-A case. The over-estimated pressure in the

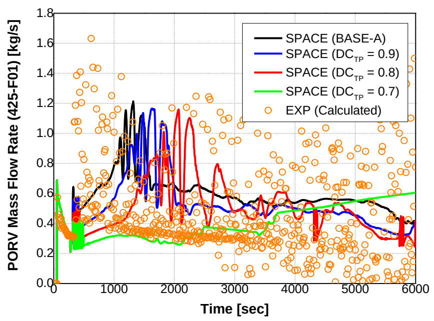

Fig. 8 Two-phase discharge coefficient effect on the PORV flow rate.

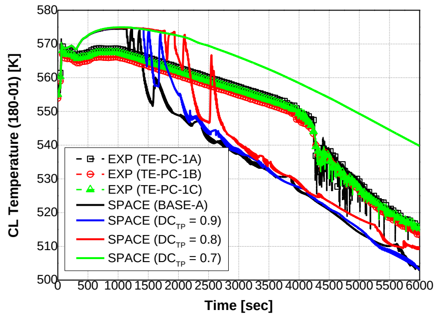

Fig. 9 Two-phase discharge coefficient effect on the cold-leg temperature.

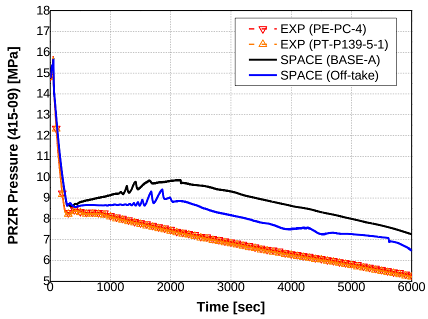

Fig. 10 Off-take model effect on the pressurizer pressure.

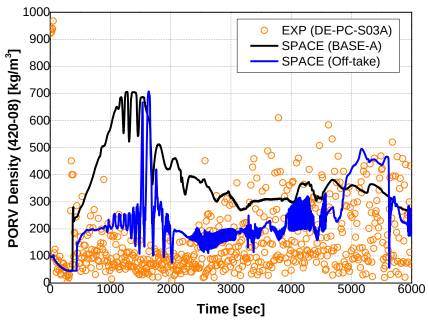

Fig. 11 Off-take model effect on the density in the PORV relief-line.

long-term transient is reduced by the off-take model in the pressurizer surge-line (Fig.10). When the off-take model is applied, the density at the pressurizer relief-line is reduced (Fig.11), which means enthalpy discharge rate is increased. However, the density is still over-predicted. It can be a reason for over-prediction of the primary system pressure as shown in Fig. 10.

Additionally, the sensitivity tests for the MSCV leakage, the SG recirculation ratio are conducted. The MSCV leakage and the SG recirculation ratio have an influence mainly on the secondary system. When the recirculation ratio is reduced, primary pressure and temperature is slightly reduced in the short-term region due to increased heat removal capability.

4.2 Proposed Model Results

Based on the sensitivity analysis results, the vapor DC of 1.2 and the two-phase DC of 0.9, additional heat loss in the primary system of 0.5%, the off-take model are applied. Fig. 12 and Fig. 13 shows the improved prediction for the pressurizer pressure and the HL temperature, respectively. The most dominant parameters during the short-term and the long-term transients are the vapor DC and off-take model, respectively.

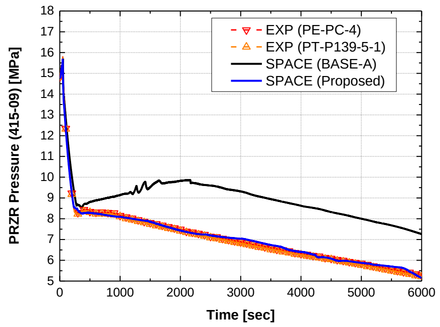

Fig. 12 Comparison of the pressurizer pressure between the base and proposed cases.

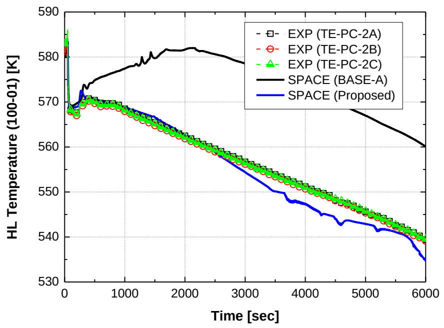

Fig. 12 Comparison of the hot leg temperature between the base and proposed cases.

5. Summary

The LOFT LP-FW-1 test was simulated a total loss of feed-water (TLOFW), which is one of initiating events categorized in the design extension condition (DEC). In this study, the LOFT LP-FW-1 is analyzed using SPACE code in order to evaluate the analysis capability and to give a basis of analysis methodology for the DEC events. In the pre-analysis, the prediction of a short-term transient is reasonable except a little delay. However, in a long-term transient, the overall pressure and temperature are over-predicted.

A sensitivity analyses for the selected parameters are carried out. The most sensitive parameter is the discharge coefficient in the PORV and the off-take model in pressurizer surge-line. When the PORV is opened, the vapor phase is initially discharged. When the liquid level in the pressurizer reaches the top and two-phase mixture begins to be discharged, which results in a re-pressurization of the primary system. When vapor discharge coefficient is increased to 1.2, the reduction rate of primary system pressure during the short-term is well predicted. When the off-take model is applied to the pressurizer surge-line, the primary system re-pressurization is reduced due to lower density in the pressurizer relief-line. In addition, the heat loss can be effective parameter to reduce the system pressure and temperature.

In the near future, to obtain the accurate SPACE code prediction for the LP-FW-1 test, the data assimilation analysis will be conducted using a PAPIRUS program with refined input parameters and reasonable uncertainty band.

Acknowledgement

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