Analysis on a Letdown Line Break Event for OPR1000 Plant Using SPACE

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1. Introduction

According to Section 15.6.2 of US Nuclear Regulatory Commission (NRC) Standard Review Plan (SRP) [1], radiological consequences of the leak through a small line carrying primary coolant outside containment shall be analyzed. In OPR1000 plant, a double-ended break of the letdown line outside containment was selected for this event category since it may result in the largest release of primary coolant to the environment. A break of the letdown line outside containment, Letdown Line Break (LDLB) event, results in a direct release of primary coolant to the auxiliary building. In this study, an LDLB event on OPR1000 plant is analyzed using SPACE [2] and the results are compared with the results of CESEC-III [3] analysis.

2. Overview of LDLB event

The analysis of an LDLB event for Chapter 15 of Safety Analysis Report (SAR) is performed with respect to radiological consequences using a conservative approach. The radiological consequences of an LDLB event could be maximized by increasing the total released mass and increasing the flashing at the break. In accordance with SRP [1], the break flow is assumed as critical flow at the break location. Moreover, the flashing fraction at the break is determined by assuming the discharge to be an isenthalpic process.

The LDLB event results in a drastic decrease in RCS pressure due to a large release of the primary coolant. The release is terminated by the closure of letdown line isolation valve on Safety Injection Actuation Signal (SIAS). Thus, the total released mass of primary system can be maximized by delaying the SIAS.

The letdown flow passes through the tube side of the Regenerative Heat Exchanger (RHX) and cooled by the charging flow in the shell side of the RHX before being released outside containment, which decreases the flashing at the break. Therefore, RHX model is required to properly evaluate the flashing fraction.

3. Analysis of LDLB event for OPR1000 plant

3.1. CESEC-III analysis method of LDLB event

CESEC-III computer code is utilized for the simulation of an OPR1000 Nuclear Steam Supply System (NSSS). The code calculates the plant response for non-LOCA events with a wide range of operating conditions [3]. The nodalization of CESEC-III is shown in Figure 1. The letdown line break model of CESEC-III calculates the pressure drop in the letdown line and the heat transfer in the RHX. A critical flow is assumed at the break location in CESEC-III LDLB model which iteratively calculates the break flow by assuming single-phase flow in the letdown line is equal to the critical flow assumed at the break location. The enthalpy decrease of the letdown flow through the tube side of RHX is considered in the calculation of the break flow. The flashing fraction for each time step is calculated by assuming that the enthalpy of single-phase is equal to the two-phase mixture enthalpy of flashed fluid at atmospheric pressure.

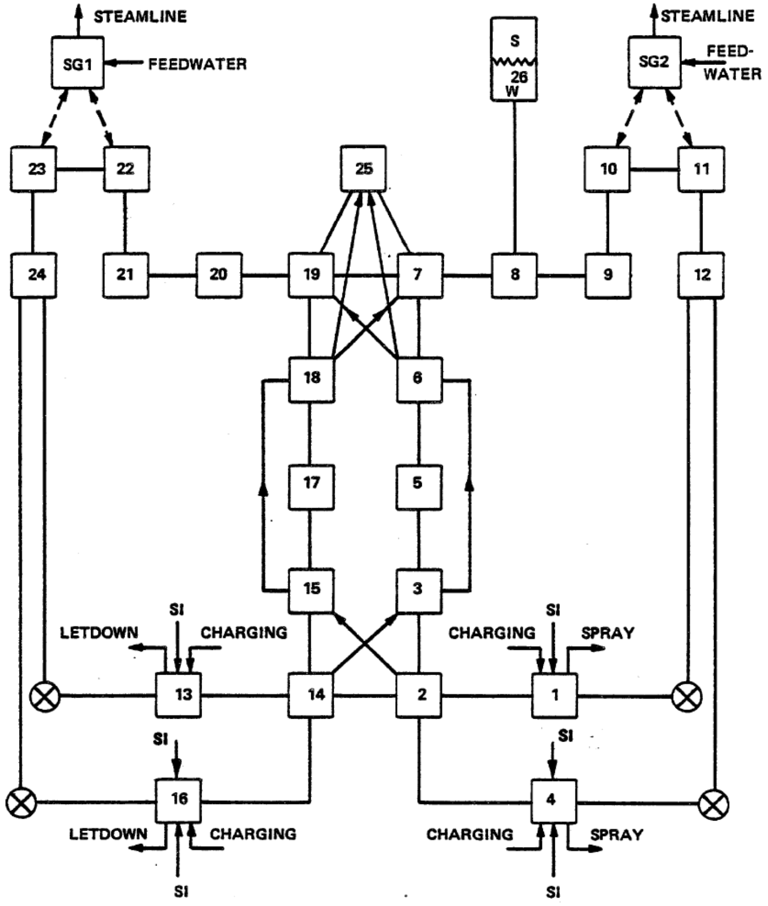

Fig. 1. CESEC-III nodalization

3. Analysis of LDLB event for OPR1000 plant

3.2. SPACE analysis method of LDLB event

SPACE is a general purpose multi-dimentional best-estimate safety analysis code [2]. SPACE version 3.22 is used. SPACE nodalization of OPR1000 plant for LDLB analysis is shown in Figure 2, which includes RHX and the charging/letdown piping. The RHX is directly modeled from component design data and drawings. A preliminary analysis with SPACE showed that critical flow condition is not established during the event due to the pressure drop in the letdown line and the temperature drop in the RHX. Thus, the estimated break flow is smaller in SPACE analysis than that of CESEC-III analysis. During the event, part of the letdown flow flashes into steam inside the letdown line due to the pressure drop in the letdown line piping. The remaining liquid is assumed to be flashed into steam at the break with the calculated flashing fraction. The method of calculating flashing fraction is the same as that of CESEC-III.

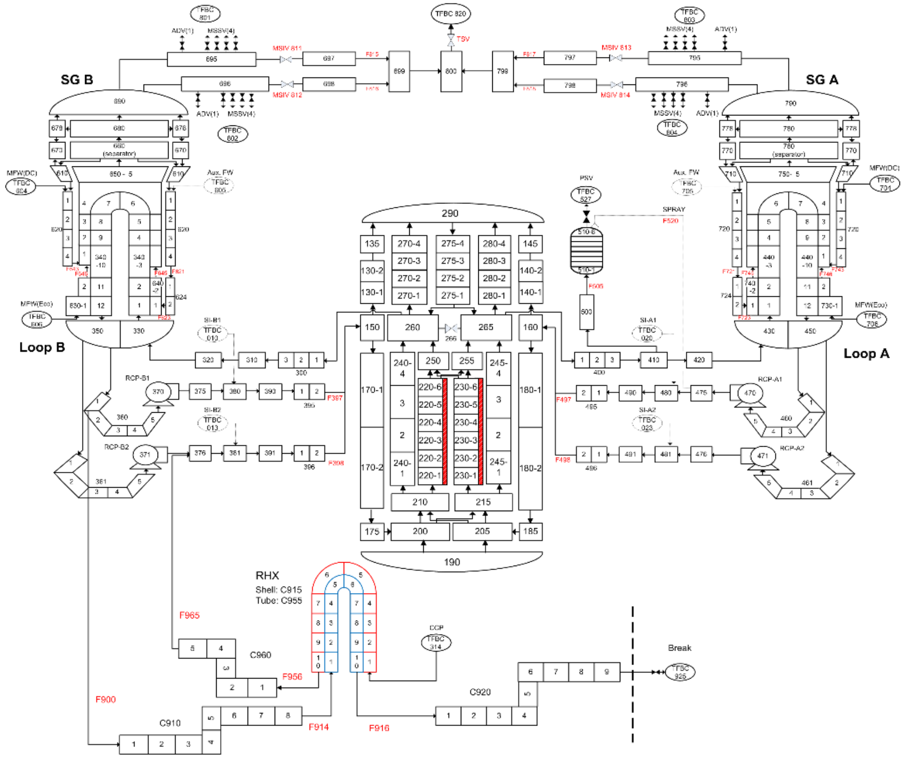

Fig. 2. SPACE nodalization of OPR1000 for LDLB analysis

3. Analysis of LDLB event for OPR1000 plant

3.3. Assumptions and initial conditions

Initial conditions for the analysis are selected to maximize the total released mass and the flashing fraction at the break. The total released mass is maximized by delaying the SIAS and the flashing fraction is maximized by increasing RCS fluid enthalpy. A preliminary analysis was performed to determine the limiting initial conditions. The limiting case was selected based on the integrated flashed mass.

A Loss of Offsite Power (LOOP) is not considered in the analysis since it causes the closure of the letdown line isolation valves, which results in less severe radiological consequences. The maximum charging flow is assumed in order to delay the generation of SIAS. Assumptions and initial conditions used in SPACE analysis and CESEC-III analysis are the same as summarized in Table I.

Table I: Assumptions and initial conditions for LDLB

Parameters	**CESEC-III**	**SPACE**
Core Power	Max.	Same as left
Core Inlet Temperature	Min.	
Pressurizer Pressure	Max.	
Core Flow Rate	Max.	
Pressurizer Water Volume	Max.	
MTC	Least (-)	
FTC	Least (-)	
Break Size	Double-ended	
LOOP	Not assumed	
Charging Flow	Max.	

3. Analysis of LDLB event for OPR1000 plant

3.4. Analysis results

The sequence of events during LDLB is shown in Table II and major parameters during LDLB event are shown in Fig. 3~7. The break of the letdown line causes the primary pressure to decrease continuously. The pressurizer backup heaters are automatically turned on by low pressurizer pressure. All pressurizer heaters are turned off by low pressurizer level at around 600 seconds. Reactor trip signal on CPC hot leg saturation is generated. Pressurizer pressure constantly decreases until the letdown line is automatically isolated on SIAS.

The total discharged mass and flashed mass are provided in Table III. As shown in Table III, there is a relatively small difference between the results from CESEC-III and SPACE.

Table II: Sequence of events for LDLB

Event	**Time (seconds)**	
	CESEC-III	**SPACE**
Letdown line rupture occurs	0.0	0.0
Pressurizer backup heaters turned on	181.5	189.7
Pressurizer backup heaters turned off	595.0	658.3
CPC hot leg saturation signal generated	1,112.3	1,311.2
Trip breakers open	1,112.4	1,311.3
Main steam safety valves open	1160.4	1,347.1
Safety injection actuation signal occurs	1307.6	1,470.4
Letdown isolation valves automatically close by SIAS	1314.6	1,477.4

3. Analysis of LDLB event for OPR1000 plant

3.4. Analysis results

Table III: Results of LDLB analyses

	Integrated Discharged Mass (lbm)	Integrated Flashed Mass (lbm)	Flashing Fraction
CESEC-III	70,347	18,250	0.2594
SPACE (% diff.)	75,377 (+7.15%)	17,216 (-5.67%)	0.2284 (-12.0%)
SPACE – Case A (% diff.)	73,160 (+4.00%)	17,178 (-5.87%)	0.2348 (-9.48%)
SPACE – Case B (% diff.)	70,223 (-0.18%)	16,480 (-9.70%)	0.2347 (-9.52%)

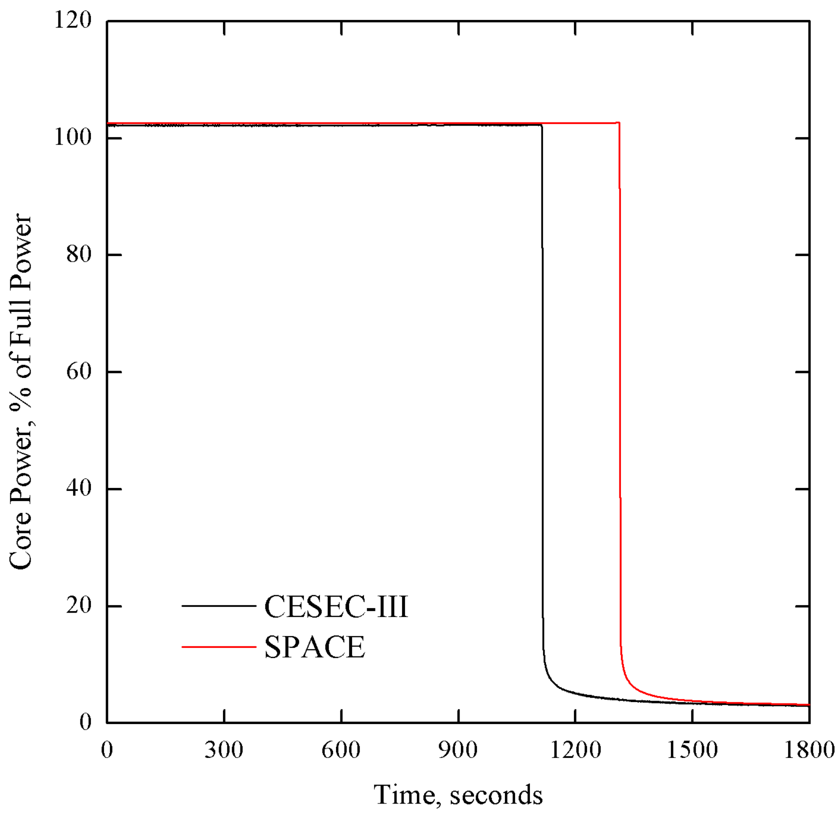

Fig. 3. Core power

3. Analysis of LDLB event for OPR1000 plant

3.4. Analysis results

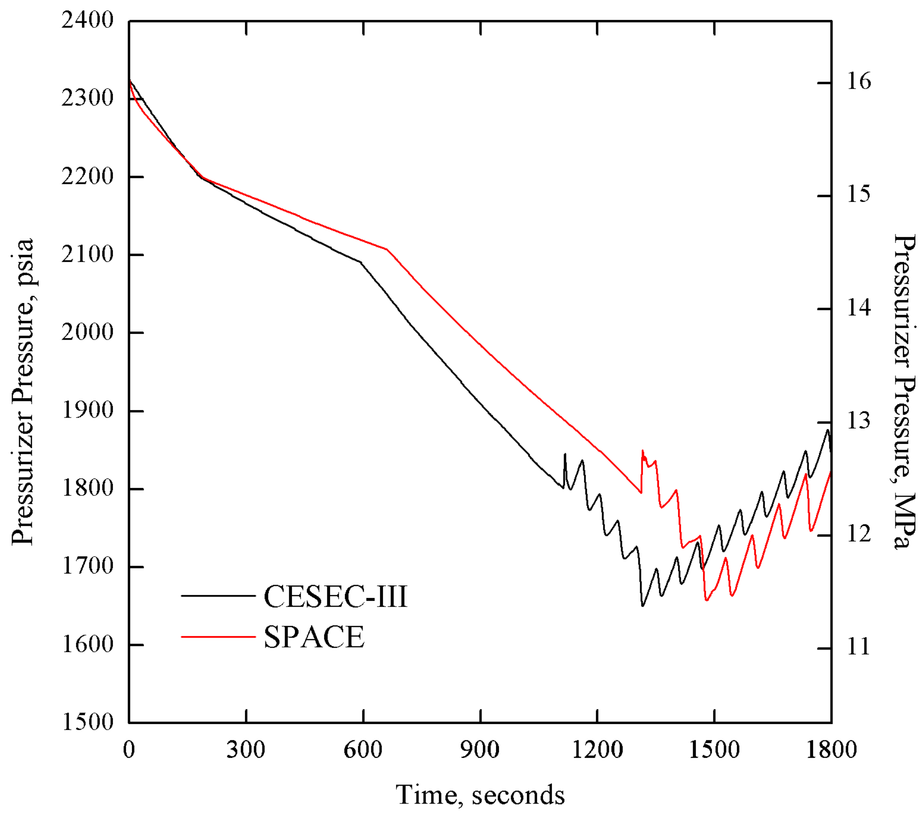

Fig. 4. Pressurizer pressure

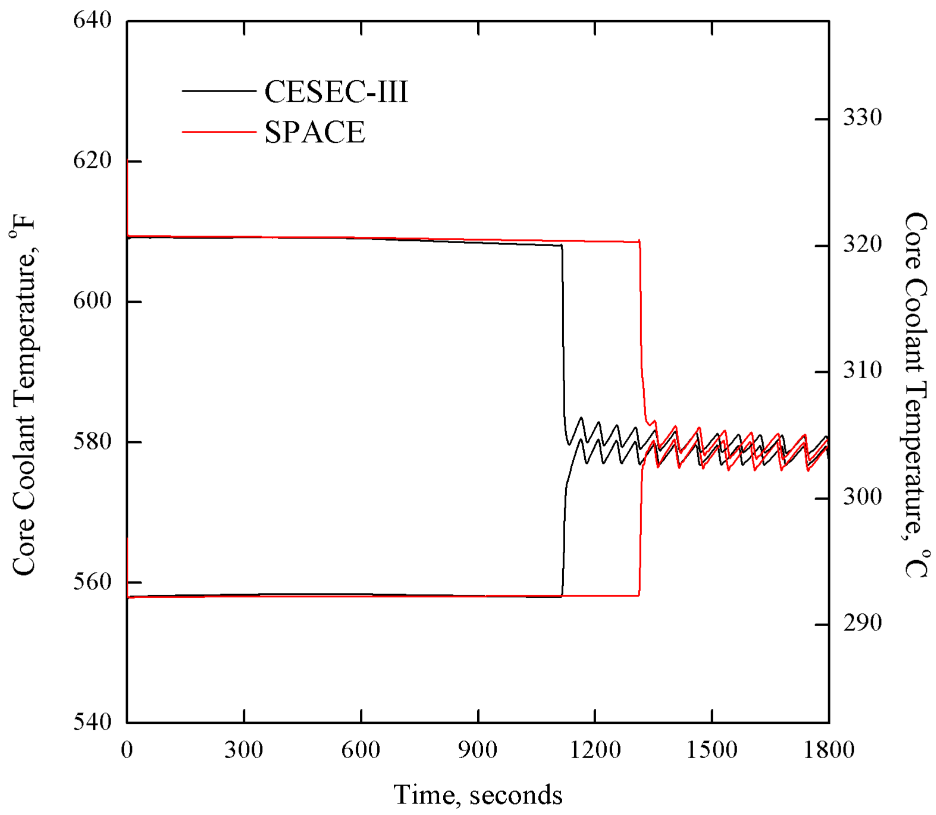

Fig. 5. RCS temperature

3. Analysis of LDLB event for OPR1000 plant

3.4. Analysis results

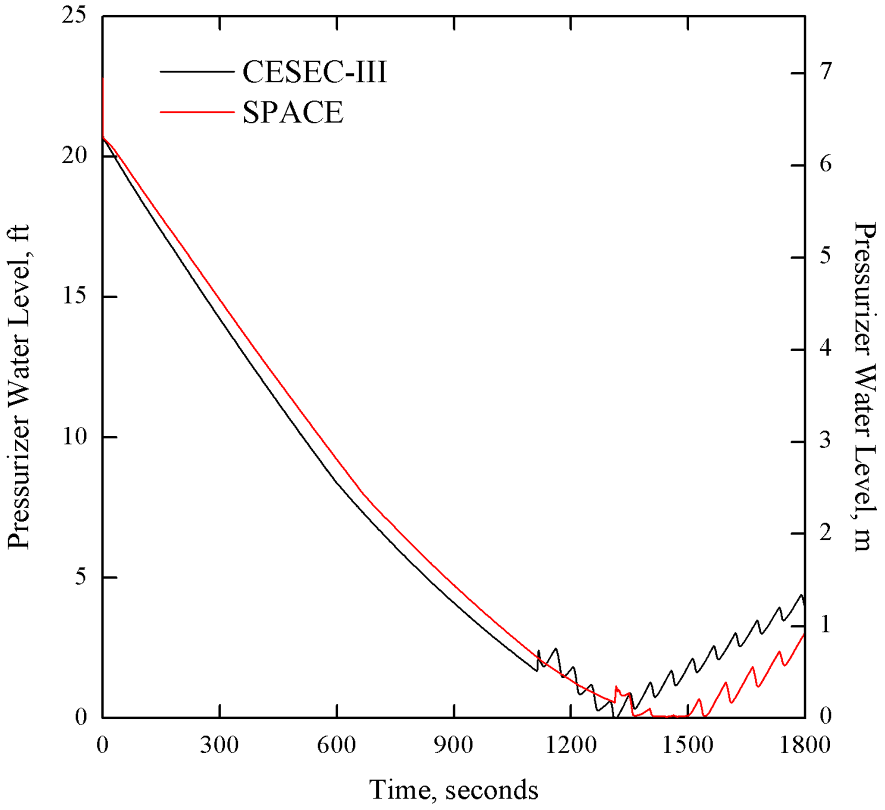

Fig. 6. Pressurizer water level

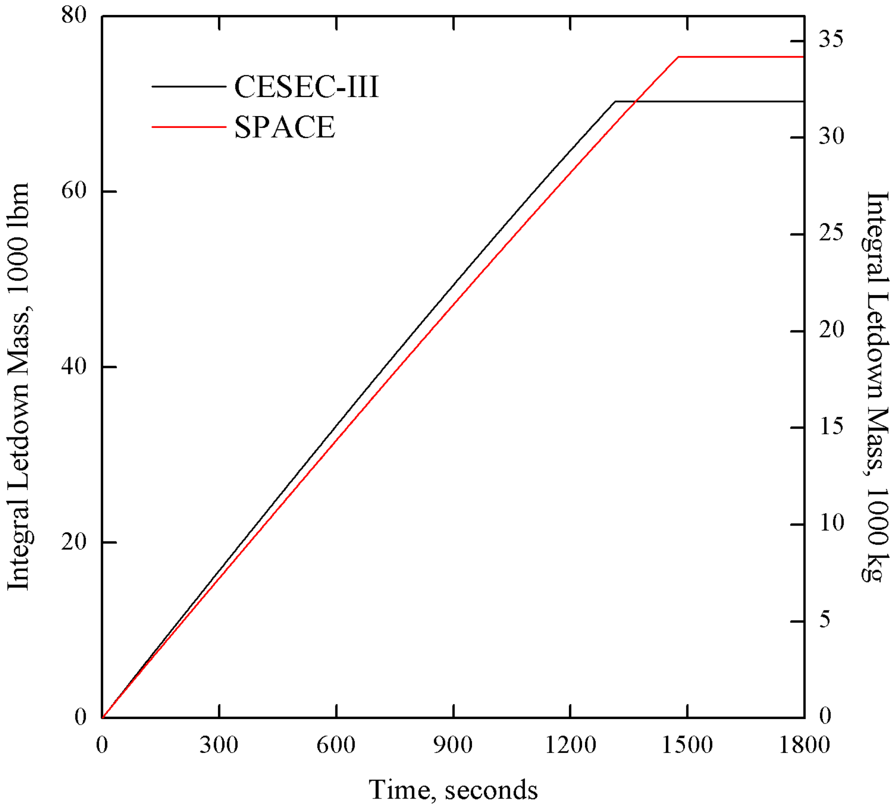

Fig. 7. Integrated letdown mass

3. Analysis of LDLB event for OPR1000 plant

3.4. Analysis results

The total discharge is 7.15% larger in SPACE analysis. The difference in the total discharged mass can be explained by (1) the difference in the break flow rate, and (2) the absence of pressurizer (PZR) metal model in CESEC-III. Since the break flow is conservatively assumed in CESEC-III analysis, the break flow is smaller in SPACE analysis. This is the main reason that the letdown line isolation on SIAS is delayed in SPACE analysis. Moreover, in SPACE analysis which includes PZR metal, PZR pressure decrease due to the primary coolant discharge is compensated by the addition of heat from the PZR metal. This slowdown of the rate of de-pressurization leads to a delayed isolation of letdown line on SIAS. Two additional cases are analyzed to evaluate the effects described above, the difference in the break flow rate and the PZR metal model. In Case A, the total flow resistance is decreased, so that the initial break flow in SPACE analysis is approximately equal to that of CESEC-III analysis. In Case B, in addition to the decreased flow resistance, the heat capacity of PZR metal is assumed as zero, so as to eliminate the effect of PZR metal during the transient. The results from additional cases are shown in Fig. 8~10. The result of Case B shows better agreement with the result of CESEC-III analysis in terms of the rate of depressurization and the time point of letdown line isolation on SIAS.

3. Analysis of LDLB event for OPR1000 plant

3.4. Analysis results

The total flashed mass in SPACE analysis is 5.67% smaller than that in CESEC-III analysis, since the average flashing fraction is evaluated to be 12.0% smaller than CESEC-III analysis. Further study is needed on the degree of conservatism regarding the heat exchange with the charging flow in RHX model during the LDLB analysis.

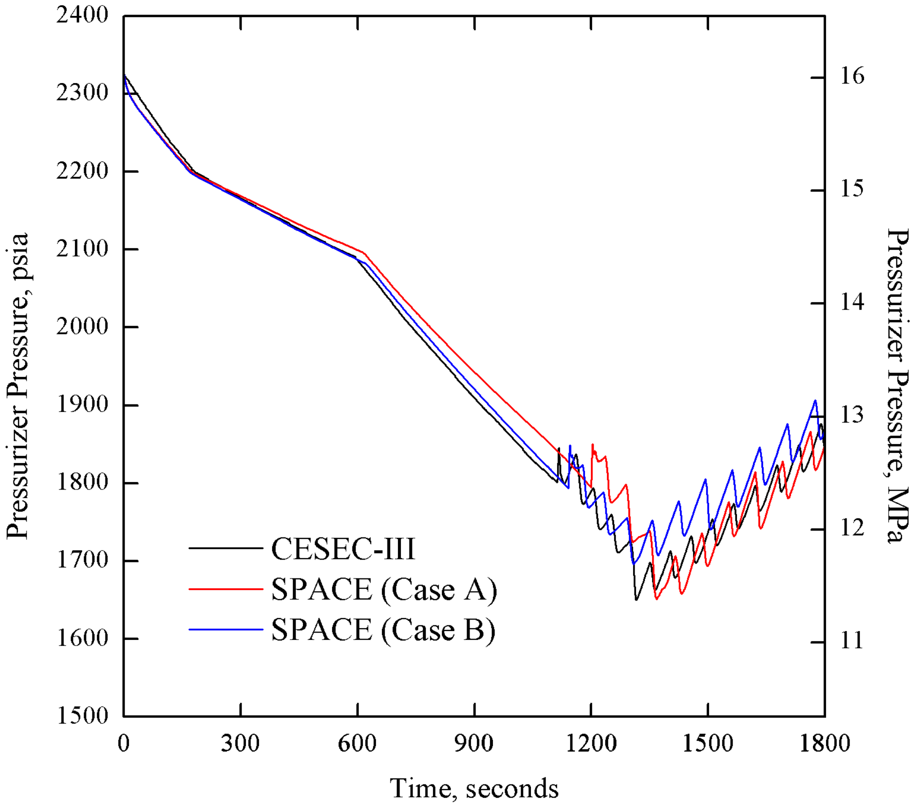

Fig. 8. Pressurizer pressure (Case A/B)

3. Analysis of LDLB event for OPR1000 plant

3.4. Analysis results

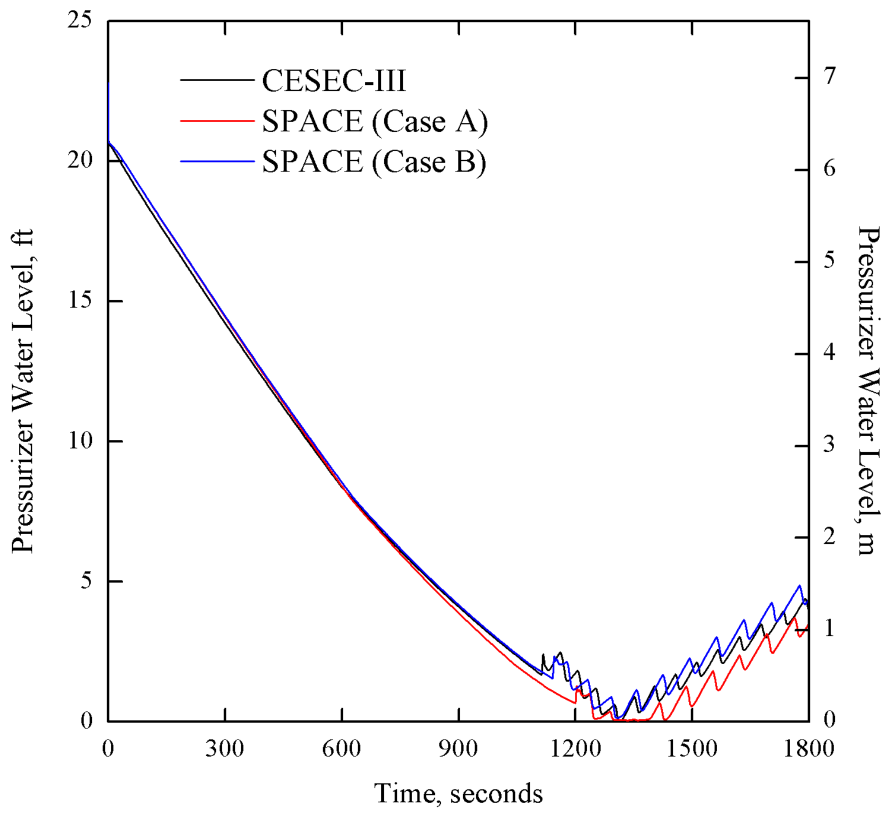

Fig. 9. Pressurizer water level (Case A/B)

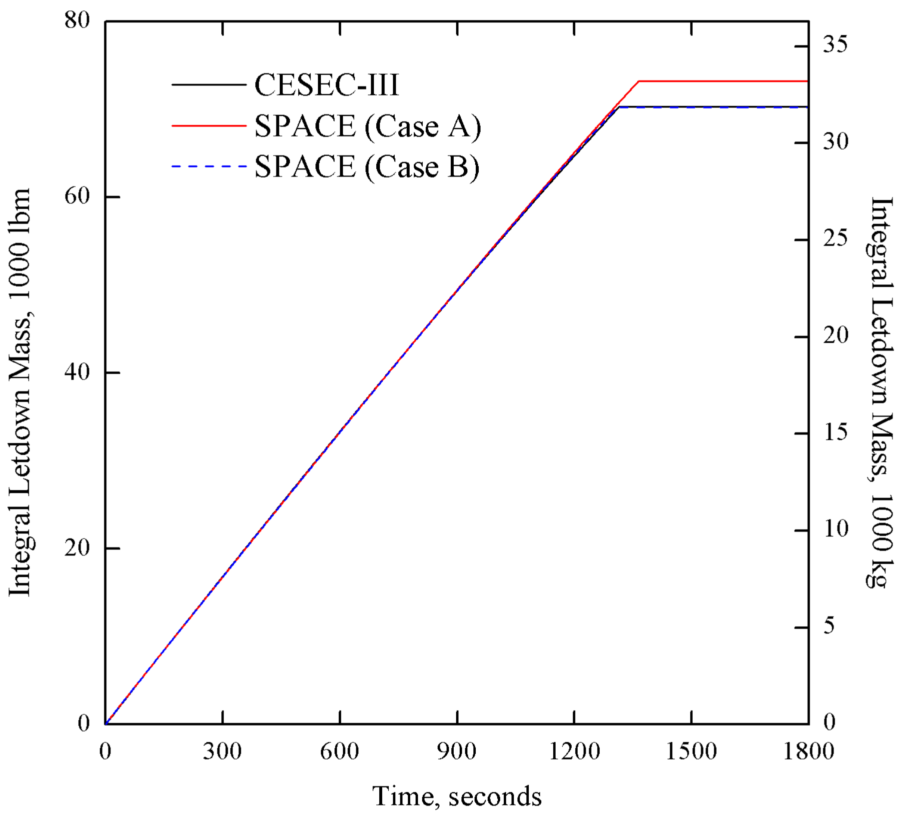

Fig. 10. Integrated letdown mass (Case A/B)

4. Conclusion and further study

In this study, LDLB event on OPR1000 plant is analyzed using SPACE and the results are compared with those of CESEC-III analysis. It is concluded that LDLB analysis of SPACE agrees reasonably well with that of CESEC-III. Further studies on the effect of PZR metal, RHX model including charging flow and different break sizes are required.

REFERENCES

[1] US NRC, “Standard Review Plan,” NUREG-0800.

[2] KHNP, “Topical Report on the SPACE code for Nuclear Power Plant Design,” TR-KHNP-0032, March 2017.

[3] CENPD-107, “CESEC Digital Simulation of a Combustion Engineering Nuclear Steam Supply System,” April 1974.