Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

TMI Steam Line Break Simulation using SPACE

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1. Introduction

KNF is currently developing the transient analysis methodology based on three dimensional core simulation. As the first step of the development, three dimensional core kinetics code and system T/H analysis code (SPACE) have been coupled. And the coupled code will be verified through NEA/NSC TMI Main Steam Line Break (MSLB) benchmark problem [1]. As an early stage of the verification, TMI-1 two-loop SPACE input for MSLB simulation was generated and verified.

In this paper, SPACE TMI MSLB analysis results using point-kinetics model are described.

2. Description of TMI MSLB

2.1 TMI Plant Nodalization

Figure. 1 shows SPACE nodalization of TMI-1. All geometric data of TMI-1 plant have been referred to "Volume I of PWR Main Steam Line Break Benchmark" [1].

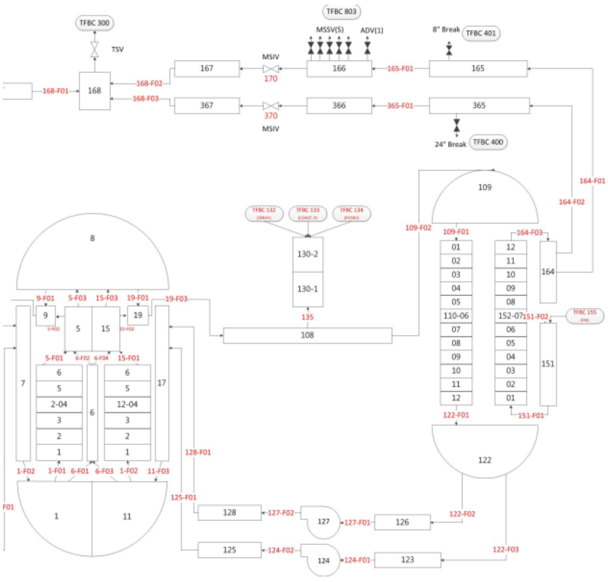

Fig. 1. TMI-1 SPACE nodalization diagram (left side loop is omitted)

2.2 Initial Conditions

The initial operating conditions are as follows: the initial RCS pressure is 2,170 psia (the normal operating value), the initial pressurizer liquid level is set to 220 temperature-compensated inches (a typical HFP level) and the initial cold leg temperature is at the normal value of 555 °F. The limiting MSLB for TMI-1 is at hot full power (HFP) because the amount of steam release and cool-down are maximized with the assumption of HFP. An initial steam generator inventory of 57,320 lbm (26,000 kg) is assumed. Once-through steam generator (OTSG) generates the super-heated steam 35 ˚F higher than its saturation temperature. Table I gives a detailed description of the initial steady state conditions for MSLB transient.

Table I: Initial conditions for TMI-1 at 2772 MWt

	Unit	Ref.[1]	SPACE	Error[%]
Core power	MWt	2772.0	←	0.00
Cold leg temperature	˚F	555.0	554.95	-0.01
Hot leg temperature	˚F	605.0	605.15	0.02
Lower plenum pressure	psia	2228.5	2230.50	0.09
Outlet plenum pressure	psia	2199.7	2199.53	-0.01
RCS pressure	psia	2170.0	2170.42	0.02
Total RCS flow rate	lb/sec	38806.2	38806.20	0.00
Core flow rate	lb/sec	35389.5	35392.53	0.01
Bypass flow rate	lb/sec	3416.7	3413.67	-0.09
Pressurizer level	inches	220.0	220.21	0.10
Feedwater flow per SG	lb/sec	1679.0	1662.65	-0.98
SG outlet pressure	psia	930.0	927.11	-0.31
SG outlet temperature	˚F	571.0	571.02	0.00
SG superheat	˚F	35.0	35.54	1.54
Initial SG inventory	lbm	57320.0	57317.33	0.00
Feedwater temperature	°F	460.0	460.00	0.00

2.3 Assumption of MSLB analysis

The double-ended rupture of one steam line is assumed to occur upstream of the MSIVs at the cross-connect. The rupture of the 24 inch (60.96 cm) outer diameter main steam line (this is the largest possible break) results in the highest break flow and maximizes the RCS cool-down.

Since maximizing the primary to secondary heat transfer results in maximum RCS cool-down, all four RCS pumps are assumed to operate during the event. No credit is taken for pressurizer heater operation. This conservative assumption enhances the RCS depressurization.

The reactor trip is modelled to occur when the neutron power reaches 114% of 2,772 MWt, or when the primary system pressure at the hot leg pressure tap reaches 1,945 psia (13.41 MPa). A trip delay of 0.4 seconds is used for the high neutron flux trip, while the low RCS pressure trip delay is 0.5 seconds.

The high-pressure injection (HPI) system initiates with a 25 second delay when the primary system pressure drops to 1,645 psia (11.34 MPa). HPI is expected to activate because of the large overcooling which occurs during this simulated MSLB transient.

A summary of the input values for the point kinetics analysis is shown in Table II.

Table II: Input values for the point kinetics analysis

Parameter	Value [1]	
MTC	-34.64 pcm/F	-62.35 pcm/K
DTC	-1.43 pcm/F	-2.57 pcm/K
Prompt neutron lifetime	0.18445E-4 sec	
Tripped rod worth	4.526 % dk/k	
	Decay constant, (1/s)	Fraction of delayed neutron (%)
Group 1	0.012818	0.0153
2	0.031430	0.1086
3	0.125062	0.0965
4	0.329776	0.2019
5	1.414748	0.0791
6	3.822362	0.0197
Total fraction of delayed neutron	0.5211 %	

The conservative assumption of feedwater flow to the broken SG (Fig. 2) helps to maximize the cool-down.

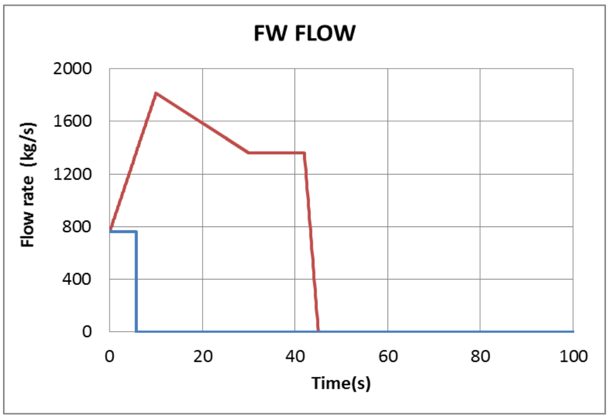

Fig. 2. Assumption of feedwater flow rate

2.4 Results of MSLB analysis

The major parameter behaviors of TMI MSLB transient analysis are shown in Figure 3 to 8.

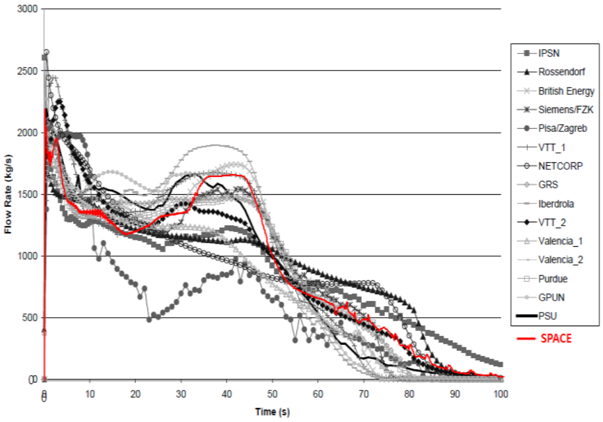

Fig. 3. Total break flow rate

The steam release caused by MSLB decreases broken loop pressure (Fig. 4) and average coolant temperature (Fig. 5).

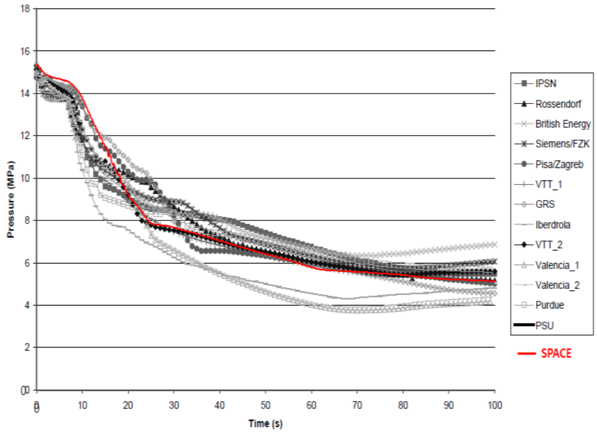

Fig. 4. Broken loop pressure

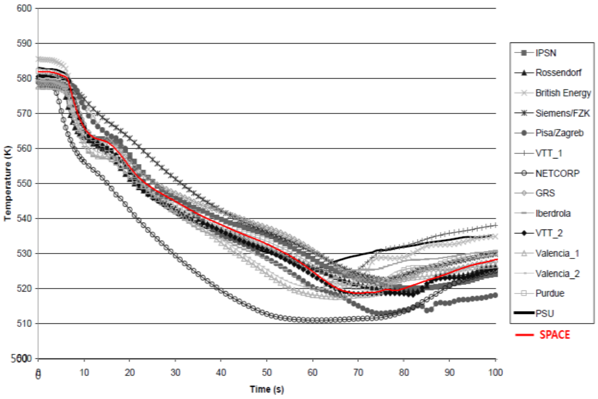

Fig. 5. Average coolant temperature

Figure. 6 shows fuel average temperature during the MSLB simulation. The fuel average temperature decreases after reactor trip and then it turns to increase with increasing core power. The behavior of broken steam generator mass is shown in Fig. 7. As the assumption of feedwater flow rate, mass of broken steam generator increases and decreases.

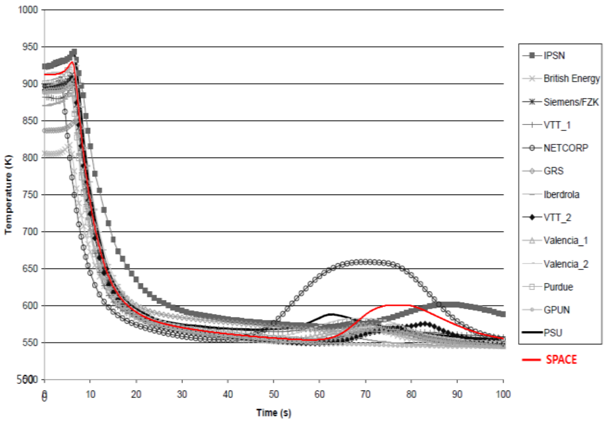

Fig. 6. Fuel temperature

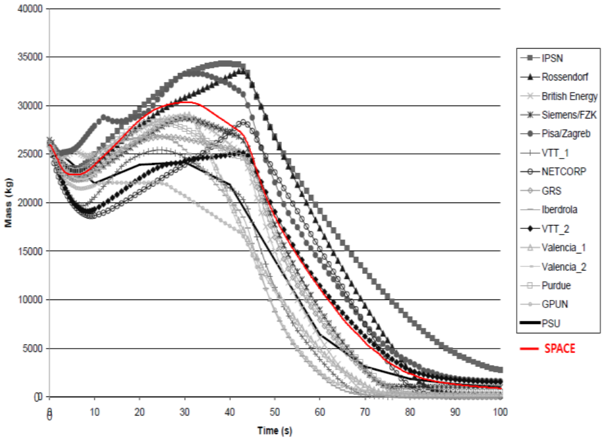

Fig. 7. Broken steam generator mass

Core power behavior is described in Fig. 8. NETCORP shows the largest deviation for the second peak, and IPSN shows the largest deviation at the end of transient. As shown in Fig. 8, total power behavior of SPACE is similar to the results of reference codes [1]

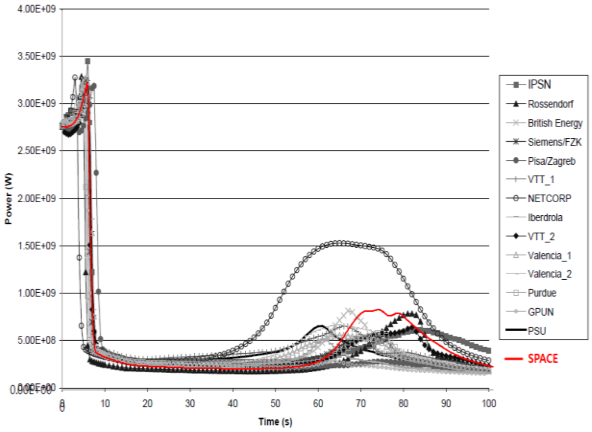

Fig. 8. Total power

The sequence of events for the PWR MSLB benchmark is described in Table III.

Table III: Sequence of events for MSLB benchmark

Event	SPACE	Purdue/ NRC	VTT 1 (SMABRE)
Break opens	0.01	0.001	0.0
Turbine isolation valve closes – broken SG	0.01	0.001	0.5
High neutron flux set point	5.32	4.5	5.7
Low RCS pressure set point	N/A	N/A	N/A
Reactor trip	5.72	4.9	6.2
Turbine isolation valve closes – intact SG	5.72	5.4	6.6
Steam line B safety valve Group 1 opens	7.10	6.6	7.4
Steam line B safety valve Group 2 opens	7.10	6.6	7.4
Steam line B safety valve Group 3 opens	10.40	7.7	7.6
HPI initiated	14.21	10.0	10.9
Steam line B safety valve Group 3 closed	15.40	14.7	28.1
Steam line B safety valve Group 2 closed	22.80	31.8	34.9
Steam line B safety valve Group 1 closed	22.80	17.9	34.9
HPI starts	39.21	35.0	35.9
Return to criticality	63.70	67.2	Not described
Point of maximum power after trip	73.40	73.5	66.0
Transient ends	100.0	100.0	100.0

3. Conclusions

TMI MSLB benchmark problem (point-kinetics) has been simulated by SPACE code. SPACE shows reasonable behavior comparing to the analysis results of other organizations. In conclusion, SPACE model of TMI has been verified through MSLB benchmark problem. In the near future, the developed SPACE TMI model will be used to verify the coupled code of three dimensional core and T/H system code.

REFERENCES

[1] T. Beam, K. Ivanov, B. Taylor and A. Baretta, Pressurized Water Reactor Main Steam Line Break (MSLB) Benchmark, Dec 2000.