Evaluation of Shutdown LOCA for OPR1000

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1. Introduction

In Korea since a steam generator tube rupture (SGTR) happened during shutdown operation for Ulchin 4 Nuclear Power Plant (UCN4 NPP) on April 2002, the KINS staff has indicated to improve the current emergency operation guideline. In NUREG-1449 [1] NRC staff evaluations of shutdown operations indicate that recommendations have been implemented and/or are underway at operating plants. Accordingly KOPEC has performed that a systematic Generic Emergency Operation Guideline (Generic EOG) or Generic Technical Guideline (GTG) will be established to enhance the safety of Optimized Power Reactor (OPR) 1000 (so-called as Korean Standard Nuclear Power Plant, KSNP) in occurring accidents of loss of reactor coolants or SGTR during shutdown operation. The purpose of the paper is to provide the basis for Generic EOG as the result of this evaluation of small break loss of coolant accident (SBLOCA) during modes 3 and 4 of OPR1000.

2. Analysis Methods and Results

2.1. Elimination of the LBLOCA Evaluation

The shutdown LOCA involves the use of leak-before-break (LBB) technology to define the maximum credible break size to be considered for shutdown conditions; and a LOCA analysis to determine the available operator action time to mitigate the consequences of the maximum credible LOCA. The regulatory staff may indicate that an exemption to 10CFR50.46 may be required in conjunction with the technical justification. However, OPR1000 has already designed with LBB technology on pressurizer surgeline, safety injection line to cold leg, and shutdown cooling line to hot leg as well as main loop piping. Also recent USNRC initiative for the revision of 10CFR50.46 [2] defines the transition break as 14 inches based on the largest piping of pressurizer surgeline. Any breaks larger than that is considered to occur on the main loop piping and large break is considered to have precursors such as LBB. Therefore the large break LOCA is not accounted appropriate for shutdown operation, so that only SBLOCA is considered.

2.2. Acceptance Criteria, Methods and Model

The acceptance criteria of ECCS performance analysis for shutdown operation mode LOCA's is established to be the same as those for power operation mode 1, which are described in 10CFR50.46.

The SBLOCA analyses are performed using RELAP5/MOD3.3 code [3] and MARS3.0 [4] which has been developed for best-estimate transient simulation of light water coolant systems during postulated accidents. The code models the coupled of the reactor coolant system (RCS) and the core for LOCAs and operational transients. A generic modeling approach is used that permits simulating a variety of thermal hydraulic systems. Especially the code has been very well predicted and widely applied to SBLOCA simulation by the members of international code assessment program, and code assessments and maintenance program for more than 20 years.

The analysis is performed for UCN 3&4 of the typical OPR1000 consists of a two-loop nuclear steam supply system and each loop contains two reactor coolant pumps and a u-tube steam generator with associated piping and valves. The code modeling of SBLOCA analysis for the whole plant is shown in Figure 1 that consists of 223 volumes and 268 junctions, and 309 heat structures and 1521 mesh points.

2.3. Analysis of the Steady-State for Power and Shutdown Operations

Before a shutdown SBLOCA transient can be analyzed, steady-state conditions of the plant must be obtained for a full power (mode 1) and zero power (modes 3 and 4), respectively.

Transient are accomplished by first performing steady-state calculations to achieve plant operating conditions of full power, then performing the steady-state of shutdown transient calculations, restarting them from full power steady-state conditions. As a result, the transient analysis has good reached to the steady-state.

It is necessary to get the shutdown steady-state conditions for a shutdown LOCA analysis. Among several plant conditions as shown in Table 1, above all a case of plant condition will be chosen to bound analyses to establish a generic analysis of the maximum credible LOCA during shutdown operation to determine the available time for operator action to mitigate the consequences of the LOCA for OPR1000. It is determined to case C3 in Table 1 (approximately 1371psia and 350^{o}F) since these conditions will be more limiting than those which will exist subsequently in modes 3 and 4. Therefore it is also accomplished by second performing steady-state calculations to achieve plant shutdown conditions of it, and the calculation is restarted from the full power steady-state conditions.

The results obtained from calculation present good agreement between both conditions.

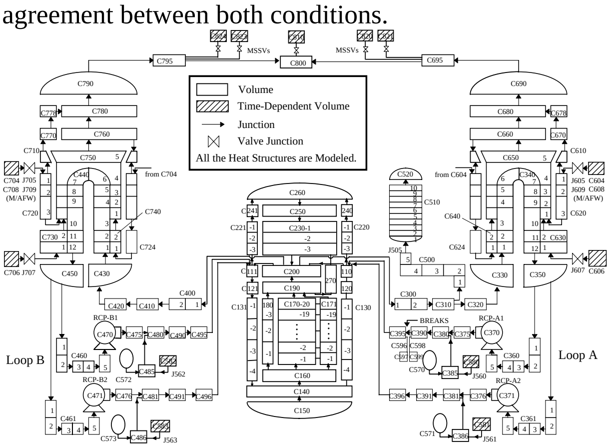

Figure 1. RELAP5 nodalization for UCN3&4 shutdown SBLOCA analysis

Table 1. Initial conditions and ECCS availability of modes 3 and 4 for a shutdown steady-state calculation

PC& Mode	RCS Pr. (psia)	CL Temp. (^{o}F)	ECCS (No. of Available Train/Setpoint Pr.(psia) HPSIP	SIT	LPSIP	Bound PC
A3	A3>1871	A3>350	2/1771	4/625	2/174	M-1
B3	1871>B3>1771	B3>350	2/1371	4/625	2/174	M-1
C3	1771>C3>640	C3>350	1/1371	3/625	1/174	M-F4
D3	640>D3>430	D3>350	1/300	3/415	1/174	M-F4
E3	430>E3>400	E3>350	1/300	N/Av. (3/300)	1/174	M-F4
C4	1771>C4>640	350>C4	1/1371	3/625	N/Av.	M-F4
D4	640>D4>430	350>D4	1/300	3/415	N/Av.	M-F4
E4	430>E4>400	350>E4	1/300	Isol.* (4/300)	N/Av.	M-F4
F4	400>F4	350>F4	N/Auto. (Opr Act.)	Isol.* (4/300)	N/Av.	Analysis

* Upon SIAS reception, isolation valves open automatically at 300 psia.

2.4. Analysis of SB LOCA during Shutdown Operation

The analysis is utilized to determine the time available for an operator to initiate safety injection (SI) flow to prevent the clad from exceeding Appendix K limits. The maximum credible size LOCA is analyzed since the operator action time to initiate SI for this break will be bounding for all of small break sizes. As a result of scoping analysis using no SI flow (F4 in Table 1) in combination with various break sizes and locations, the shutdown cooling line on hot leg (nominal 16 inches diameter) for OPR1000 is investigated to maximum credible size LOCA as a matter of course the larger break size, the faster clad heat-up beginning.

As noted previously, only the maximum credible break size LOCA is analyzed by using the safety injection tanks (SITs) and a high safety SI (HPSI) pump train on the plant shutdown conditions C3 and F4 since the results for this case will represent the minimum time available for SI initiation. As shown in Figure 2, if SITs open automatically at 300psia of RCS pressure and operator initiates at 10 minutes from break occurrence using an available HPSI train, Figure 3 shows that cladding has no heat-up during the LOCA. Even if it is analyzed for the less than the maximum credible break size, it also has been known to be good results. Finally, it shows that the ECCS design feature of OPR1000 is very adequate.

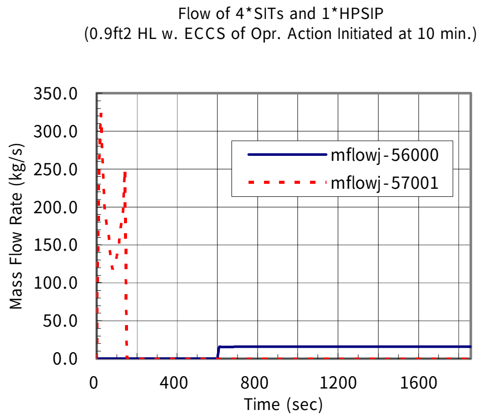

Figure 2. SI flow of SIT and HPSI

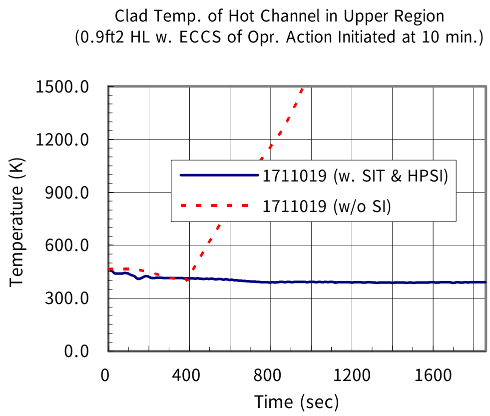

Figure 3. Cladding temperatures of hot channel

3. Conclusions

Provided that emergency core cooling flow equivalent to available SITs and one HPSI pump can be provided within a 10 minute period after lower modes 3 and 4 LOCA, it is concluded from the results of the analysis that the acceptance criteria of ECCS performance analysis for LOCAs are met.

REFERENCES

[1] USNRC NUREG-1449, Shutdown and Low-Power Operation at Commercial NPPs in the United States, 1993.

[2] USNRC, Proposed Rule: 10CFR Part 50, Federal Register, Volume 69, No 147, August 8, 2004.

[3] USNRC, RELAP5/MOD3.3 Code Manual, NUREG/CR-5535/Rev.1, January 2003.

[4] KAERI, MARS3.0 Code Manual, KAERI/TR-2811/2004, August 2004.