A methodology for Level 1 PSA Success Criteria during Mid-loop operation for Low Power Shutdown Probabilistic Safety Assessment

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1. Introduction

The primary objective of the Level 1 PSA Success Criteria during Lower Power Shutdown (LPSD) operation is to provide timing considerations for the use or restoration of support systems which enable the front-line systems to perform with regard to accident progression. The ANS LPSD PRA Standard (Reference 1) presents a specific set of requirements concerning the development of success criteria for systems and actions that are modeled in accident mitigation. Development of success criteria makes use standard computer codes, e.g., MAAP, and models developed specifically for APR1400 NPPs reactor and systems.

2. Methods and Results

In this section some of the techniques used to model the LPSD Level 1 PRA Success Criteria are described. The LPSD Level 1 PRA Success Criteria includes the definition of core damage, key safety function, and success criteria evaluation using MAAP code.

2.1 The Definition of Core Damage of LPSD Level 1 Success Criteria

The ASME/ANS PRA Standard (Reference 1) defines core damage as the uncovery and heatup of the reactor core to the point at which prolonged oxidation and severe fuel damage are anticipated. For LPSD Level 1 PRAs, NUREG/CR-6144 (Reference 2) uses 1340˚F as the definition of core damage based on phenomena of clad oxidation and ballooning. Furthermore, US NRC Inspection Manual Chapter 0609, Appendix G (Reference 3) specifies a definition of core damage as 1300˚F for LPSD PRAs. As such, 1300˚F of a peak clad temperature is used as the definition of core damage in this analysis.

2.2 Key Safety Functions

The safety functions that must be fulfilled to prevent core damage are:

- Decay heat removal;
- Inventory control;
- Reactivity control;
- Containment; and
- Pressure control

2.3 Success Criteria and Thermal-Hydraulic Analysis

Success criteria for the LPSD PSA are determined based on thermal-hydraulic analysis performed to evaluate the specific conditions specified in the accident sequence analysis. For the POS 3 through to 13 including mid-loop operation of POS 5, success criteria are analyzed using Modular Accident Analysis Program (MAAP) (Reference 4) computer code. The thermal-hydraulic analyses consider the initiating event, limiting plant conditions for each POS, and equipment availability specified for each accident sequence. As example, the success criteria of RS in POS 5, mid-loop operation, is as below.

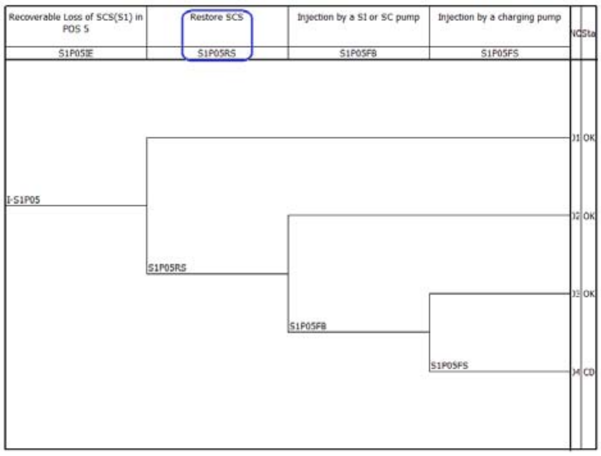

Fig. 1. Loss of SCS Event Tree in POS 5

RS (Restore SCS) : This top event represents restoration of decay heat removal by one train of Shutdown Cooling System (SCS). The SCS must be restored before RCS temperature and pressure exceed SCS operating limits or RCS water level lowers below that needed to support operation. The success criterion for this top event is one train of SCS operating to provide decay heat removal.

Thermal-Hydraulic Analysis Results : T/H analysis in POS 5 and 11, mid-loop operation, are performed to determine shutdown cooling limits and success criteria to restore SCS. Since the water level is at the shutdown level limit for mid-loop operation, the core boiling time is used as an indication for when shutdown cooling limits are reached. According to the table 1 and figure 2, the time to core boiling in POS 5 and POS 11 are 598 and 1,315 seconds, respectively. When one train of SCS is recovered within shutdown cooling limits, success criterion is satisfied to remove decay heat.

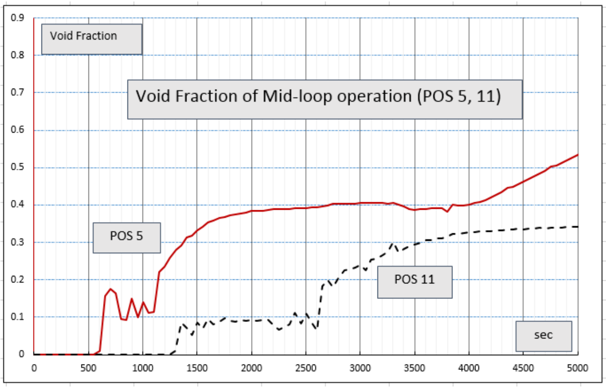

Fig. 2. Core void fraction in POS 5, 11

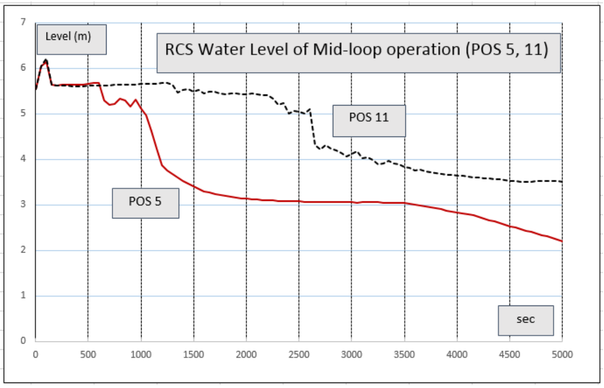

Fig. 3. RCS water level in POS 5, 11

Table 1. T/H analysis results at POS 5, 11

POS	POS 5	POS 11
Status	Before Refueling	After Refueling
Targeted RCS Initial condition	Pressure 0.1013 MPa, Cold Leg Temp. 313 K	Pressure 0.1013 MPa, Cold Leg Temp. 313 K
RCS(Initial condition)	Mid-loop operation	
SG secondary side Initial condition	Main/Aux. feedwater closed, MSIV closed	
SG secondary side(Initial condition)	ADV Close	
Analysis condition	t=0 seconds, Loss of shutdown cooling	
RCS(Peak pressure (Corresponding time))	0.142 MPa (5.9 psig), 101 seconds	0.151 MPa (7.2 psig), 102 seconds
LTOP V/V opening time	N/A	N/A
Core boiling time(t_{cb})	598 seconds	1,315 seconds
Core uncovery time(t_{cu})	4,620 seconds	11,220 seconds
Time to Core damage(t_{cf})	7,441 seconds	16,780 seconds
Time to the condition of Shutdown cooling operating limits(177oC, 31.64kg/cm2)	598 seconds (Based on time to core boiling)	1,315 seconds (Based on time to core boiling)

3. Conclusions

The Thermal Hydraulic Analyses have been performed to determine success criteria and the available time to recover SCS operation when RCS status are mid-loop operation during scheduled outage.

According to the results, if SCS operation is recovered within shutdown cooling limits such as shutdown water level or the core boiling time, success criteria are satisfied. The time to shutdown cooling limits in POS 5 and POS 11 are 598 and 1,315 seconds as time to start core boiling, respectively. These are conservative assumption.

The time to shutdown cooling limits is increased significantly due to low decay heat when core in reactor vessel is refueled. The time to shutdown cooling limit in POS 5 before offload is half of that of POS 11 because the decay heat in POS 5 is still relatively high when it is compared to that of POS 11 after refueling.

REFERENCES

[1] ANSI/ASME-58-22-2014, "Requirements for Low Power and Shutdown Probabilistic Risk Assessment," Trial Use and Pilot Application, 3/25/2015

[2] NUREG/CR-6144, "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry, Unit 1," US Nuclear Regulatory Commission, June 1994.

[3] Inspection Manual Chapter 0609, Appendix G, "Shutdown Operations Significance Determination Process," US Nuclear Regulatory Commission, February 28, 2005.

[4] Fauske and Associates, 2014, "MAAP5 – Modular Accident Analysis Program for LWR Power Plants Transmittal Document for MAAP5 Code Revision MAAP 5.03", FAI/14-0670, Rev. 1, August.