Experiences in Level 1 PSA during Low Power and Shutdown State for Wolsong 1

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1. Introduction

Level 1 PSA for internal events during the low power and shutdown state is developed selecting the possible initiating events, identifying sequence of the events for the initiating events, and analyzing the core damage frequencies for the events.

Plant Operational State (POS) should be defined for Probabilistic Safety Assessment (PSA) considering the varying system configurations including outage configurations, decay heat, plant parameters, and maintenance status. The core damage frequencies of the initiation events for each POS are calculated similarly to those of the full power internal events.

This paper is to show several specific items for the POS identification, preliminary initiating event analysis, accident sequence analysis, system analysis, and thermal hydraulic analysis of internal events for low power and shutdown state different from the full power internal events for Wolsong 1.

2. Analysis and Results

2.1 POS Identification

The operation of low power and shutdown state is composed of several operational states from a low power operation after de-synchronization to a low power operation for synchronization via shutdown state including shutdown cooling operation, surveillance tests for the safety systems and safety related systems, and outage maintenance.

Each operational state is divided depending on the power level, plant configuration for safety systems, plant parameters such as coolant pressure and temperature, and large opening areas. Although identical initiating event occurs, the times of coolant boiling and core damage can be changed and the results affect to the final core damage frequency reflecting composition of event trees and fault trees, human reliability analysis. Thus, POS identification should be divided and defined for low power and shutdown PSA considering plant operational modes, plant design concept, plant operating procedures, plant maintenance practices, etc.

For the POS identification for Wolsong 1, the operating procedures for the plant start-up and shutdown are reviewed, system configuration and plant characteristics are checked through face-to-face meeting with operators, and the maintenance practices are collected.

As the results, the POS is divided into 3 groups;

Group 1: POS 1, 2, 8A, and 8B are similar to full power operating conditions and system configurations.
Group 2: POS 3, 4, and 7 are cool-down or heat-up state without major maintenance activities.
Group 3: POS 5A, 6, and 5B have maintenance activities with drained operation.

For the specific POS identification for Wolsong 1, the following items were reviewed: plant outage schedule, cooldown and heat-up practices for several outages, decay heat level for each state, the automatic operable status of safety systems such as the emergency core cooling system and the emergency water supply system, guaranteed shutdown state, large opening time for the primary heat transport system such as the steam generator manway open, and the drained primary heat transport system.

The POS identification for Wolsong 1 consists of 10 POSs considering the above paragraph. The POS identification and duration is shown in Figure 1.

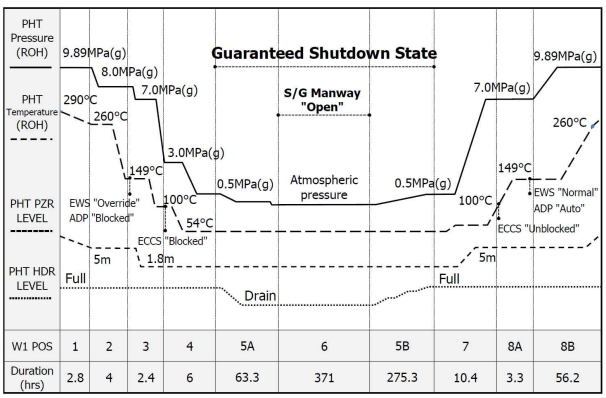

Fig. 1. POS Identification and Duration for Wolsong 1

2.2 Preliminary Initiating Events

The preliminary initiating events are reviewed considering the full power initiating events and other initiating events unique to the shutdown operation.

The initiating events different from the full power initiating events are loss of shutdown cooling and general loss of coolant accident.

2.2.1 Loss of Shutdown Cooling

Loss of shutdown cooling is defined that the heat removal function is lost during the operation of the shutdown cooling system and the core damage occurs without adequate action. This initiating event is not considered to be an initiating event because the system is not connected to the primary heat transport system and normally not operated. This initiating event can occur between POS 3 and POS 7 which the shutdown cooling system is operated as a main heat sink. While the shutdown cooling system in PWR is normally operated using 1 train, all the shutdown cooling pumps and heat exchangers in PHWR are operated. Therefore total loss of shutdown cooling was considered as an initiating event for Wolsong 1.

The main factors leading to the loss of shutdown cooling are mechanical failures of the shutdown cooling system and shutdown cooling function failures due to the auxiliary system failures. In Pressurized Water Reactor (PWR), the closure of the shutdown cooling suction valves and shutdown cooling function failures due to lowering the coolant level are additionally considered. However, the failures are not applied to the Pressurized Heavy Water Reactor (PHWR) since the shutdown cooling system has unique design feature.

While the closure of the shutdown cooling suction values can occur due to a failure of automatic closure interlock or inadequate high pressure signal in PWR, the interconnection valves between the primary heat transport system and the shutdown cooling system for Wolsong 1 are only manually operated by operator. The shutdown cooling system for Wolsong 1 is designed to be the same design pressure and temperature as those for the primary heat transport system. Therefore, it was found that the initiating event does not occur in Wolsong 1.

The loss of the shutdown cooling function occurs due to low level during the partially drained operation, the difference between minimum water level and partially drained level for Wolsong 1 is over 8 times for that of PWR. For the view of operational margin, the possibility of the initiating event is very low.

2.2.1 General Loss of Coolant Accident (LOCA)

Usually, a LOCA at full power would be categorized into Large LOCA (LLOCA) and Small LOCA (SLOCA) in which the boundary between these two categories is whether the amount of positive reactivity excursion due to void increase could be properly controlled and mitigated by the reactor regulating system (RRS). That is there was a significant difference in the rate of coolant leakage, heat transport behavior and safety system action strategy.

The definition of LLOCA and SLOCA occurred during low power and shutdown state was similar to those at full power level. However, it is not clear to distinguish which is LLOCA or SLOCA for LOCAs initiated during low power and shutdown state. Because reactor has been already tripped as well as the strategy of related safety system action would be almost identical to each other.

In PWR, the pressure and temperature in primary loop would decrease and also result in low frequency for LOCA occurrence, where a reduction factor could be applied in the core damage frequence calculation. Differently from PWR, any LOCA initiated from the SDC operation POS in PHWR would be regarded as a SLOCA and treated like a general LOCA at full power level.

During low power and shutdown state, another accident scenario related to SDC was additionally considered such as SDC line break not issued in full power operation

Aside from LOCA described above, followings categorized in LOCA were analyzed as preliminary initiation events; inadvertent Liquid Relief Valve (LRV) opening, inter-system LOCA, events which the moderator system could not be available as a heat sink, leakage through the drain line isolation valves of the shutdown cooling system, LOCA during the maintenance.

2.3 Accident Sequence Analysis

Since a main heat sink are different with auxiliary heat sink and a range of available system has a difference per each POS at low power and shutdown state, formation of event trees and accident sequence analyses are performed at each POS in the identical accident. The definition of heat sink at each POS is shown in Table 1.

Since the plant configuration during POS 1, 2, 8A, and 8B is similar to that of full power operation, the response for accident mitigation is also similar. Not like to full power operation, the shutdown cooling system is main heat sink during POS 3, 4, 5A, 6, 5B, 7. The POS 5A, 6, 5B are partially drained state up to reactor header level and thus the primary heat transport system should be filled with water for heat removal via steam generator. The POS 6 has big openings like steam generator manway, closure of which takes significant time. Therefore, system cooling using the steam generator as an auxiliary heat sink is not taken into

consideration. The emergency core cooling system is considered for system cooling for the POS 6.

Table 1. Heat Sink at each POS

Classification	Main heat sink	Auxiliary heat sink
POS 1, 2, 8A, 8B	SG	SDCS
POS 3, 4, 7	SDCS	SG
POS 5A, 5B	SDCS	SG
POS 6	SDCS	ECCS

2.4 System Analysis

The operating condition of specific system is not the same as that during full power condition depending on operational condition of the primary heat transport system and manual operation by an operator is required in the some systems. Especially main systems during POS 5A, 6, and 5B have maintenance for each train by turns or some equipment is placed unavailable. Therefore, response for accident mitigation should be different with that during full power condition and these concerns are reflected into fault tree through system analysis.

2.5 Thermal hydraulic analysis

The thermal hydraulic analysis in the PSA is performed for the purpose of establishment of each headings used in the event tree, verification of models and assumption used, and estimation of time allowed to operator for Human Reliability Analysis (HRA). Especially, the time allowed to operator to take certain actions under the specific condition is essential data for HRA. The thermal hydraulic analysis is required for observing progress of plant following accident and evaluating an allowable time for operator. And also there is a need to clarify the existing allowable time and background presented in the LPSD PSA of Wolsong 1.

3. Conclusions

Some features are discussed about differences between experience for Wolsong 1 Level 1 PSA at full power and at low power/shutdown state. Since experience and reference of PSA for low power and shutdown state are not sufficient domestically and internationally in the case of PHWR not likly pressurized light water reactors. Therefore, in the performance of PSA occurrence probability of the initialing events used in the PSA for pressurized light water reactors are considered in the respect of PHWR.

REFERENCES

[1] AECL, “Generic CANDU Probabilistic Safety Assessment-Reference Analysis”, 91-03550-AR-002, p. 283-306, 2002.

[2] AECL, Analysis Report, “Event Tree Development Wolsong234”, 86-03600-AR-003, p. 237-299, 1996.

[3] AECL, Design Manual, “Shutdown Cooling System”,DM-59-33410/63341, Rev.1, p. 19-35, 2006

[4] NRC, “Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry Unit 1”, NUREG/CR-6144, BNL-NUREG-5239, Vol.2, Part 1A, 1994.

[5] KHNP, “울진 5,6 호기 확률론적 안전성 평가, Level 1 정지저출력 PSA 최종보고서”, 2002.

[6] KHNP, “신고리 3,4 호기 확률론적안전성평가보고서, Part 4. 정지저출력 내부사건 분석”, 2011.