Thermal Hydraulic Analysis of Loss of Instrument Air for PSA of Wolsong NPP Unit 1

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1. Introduction

Loss of instrument air (IA) can occur due to compressor failures, instrument air line failures, etc. A loss of cooling to the station loads that are served by Recirculated Cooling Water (RCW) system can occur due to the loss of the RCW inventory, the loss of RCW flow and the loss of cooling to the RCW heat exchangers. Instrument air compressors are cooled by RCW. This means that a cross-link exists between RCW and instrument air. A loss of RCW can cause a loss of instrument air. These types of cross-links are either assessed during the development of the event trees or captured during the accident sequence quantification process in PSA. This paper describes the analysis of loss of IA using the thermal Hydraulic code for PSA of Wolsong NPP Unit 1.

2. Methods and Results

2.1 Overview of total loss of Instrument Air

Total loss of instrument air is defined as the condition when the compressed air supply fails to provide sufficient volume of air to required pneumatic devices at a necessary minimum pressure such that these devices go to their failed state.

Following a complete loss of instrument air with the reactor operated at 103% full power, the main feedwater regulating valves are closed fully and the auxiliary feedwater regulating valves (18% capacity) provided with local air tanks control feedwater to the steam generators. With the main feedwater regulating valves closed, the flow through the auxiliary feedwater regulating valves cannot maintain the steam generator (SG) level at full power. Reactor trip signals in shutdown system No. 1 and 2 or stepback on low SG levels are expected to occur within 1 minute after loss of instrument air. Following the loss of instrument air, heavy water would be fed at a maximum rate by the D_2O feed pump into the Heat Transport System (HTS) and there would be no bleed from the HTS. The pressure in HTS continues to increase until the high HTS pressure trip could come in.

After reactor trip, the SG pressure control program unloads the turbine in an attempt to maintain steam pressure at normal value. On failure of the SG pressure control to unload the turbine, the unloading gear unloads the turbine when the steam pressure reaches 90% of the normal value [1].

2.2 Code Modeling

Wolsong Nuclear Power Plant Unit 1 is a CANDU-6 Pressurized Heavy Water Reactor (PHWR). It has 380 horizontal fuel channels surrounded by a cool low-pressure heavy water called Moderator. Each fuel channel is six meters long and contains twelve fuel bundles within a pressure tube. The coolant enters the channel from an inlet header, and then leaves the channel through an outlet feeder pipe that is connected to the outlet header. The coolant enters the channel at approximately 11 MPa and 263℃.

In the model for the analysis, the channel groupings are based on channel power and elevation. And the model includes a detailed representation of the HTS, the detailed pressure and inventory control network and Emergency Core Cooling System (ECCS).

2.3 Assumptions

Assumptions for this analysis for total loss of instrument air are listed below.

a. Reactor is operating at 103% FP at the initial condition.
b. Reactor stepback signal on low steam generator levels is expected to occur, but not credited.
c. If the backup air supply fails to function to the auxiliary feedwater regulating valves after reactor shutdown, the level in the steam generators rises.
d. D_2O feed to the HTS is assumed to remain available during HTS cooldown.
e. There is no bleed from the HTS and the HTS can be pressurized.
f. Success criteria for the shutdown cooling system (SDCS) are one out of two shutdown cooling pumps and heat exchangers when used in normal operating mode, and two out of two shutdown cooling pumps and heat exchangers when used in abnormal operating mode.
g. If feedwater system is not available, feedwater is not supplied to the steam generators after reactor shutdown.

2.4 Event Tree

The event tree for total loss of instrument air is shown in Fig. 1. Each heading of the event tree is described below.

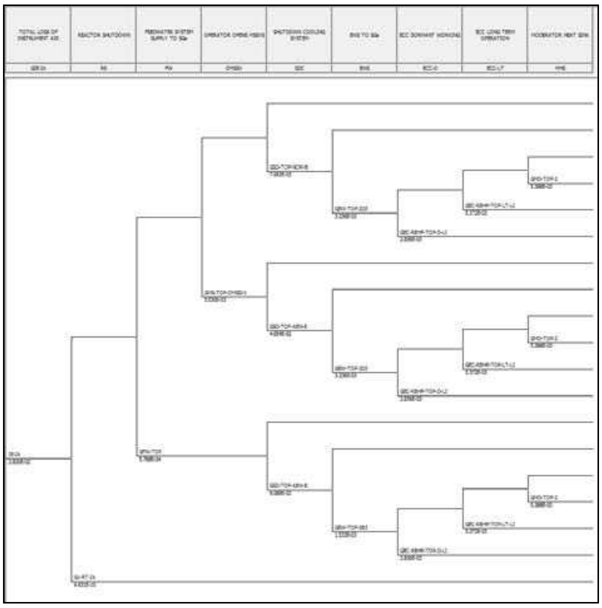

Fig. 1. Event Tree for Loss of Instrument Air

RS means Reactor Shutdown, and it can be accomplished by reactor stepback, shutdown system No. 1 or 2 on the low steam generator level or the high HTS pressure following the loss of instrument air. FW means feedwater system. In order to cool down the HTS by using the steam generators, feedwater should be supplied continuously. Any one of three feedwater pumps or the auxiliary feedwater pump supplies sufficient feedwater to the steam generators. OMSSV stands for the operator action to open the MSSV's for HTS cooldown and to gag the MSSV open for continuous cooldown of the HTS. On loss of instrument air the atmospheric steam discharge valves and the condenser steam discharge valves are fail-closed. Therefore, when the feedwater supply to the steam generators through the main feedwater pumps or the auxiliary feedwater pump is successful, the operator should open the MSSVs. SDCS represents the availability of SDCS. Success criteria are one out of two shutdown cooling pumps and heat exchangers in normal operation mode, and two out of two shutdown cooling pumps and heat exchangers in abnormal operation mode. When shutdown cooling is unavailable on demand, the steam generator should be maintained as a heat sink. The feedwater supply to the steam generators cannot last over 2 ~3 hours. Therefore, even if feedwater is successfully supplied initially, steam generator makeup water from the dousing tank or the emergency water supply is required if the shutdown cooling is unavailable. EWS means the unavailability of EWS combined with water supply from the dousing tank. Following a loss of instrument air, the heat transport system eventually drains requiring operator action to provide heat transport system make-up via the ECC. Following a loss of ECC, the moderator with the steam generators supplied from the feedwater or EWS, are assumed to act as a heat sink.

2.5 Thermal Hydraulic Analysis

Thermal Hydraulic analysis for PSA is performed to establish the success criteria in each heading used in event trees, to demonstrate the models and assurances for PSA and to calculate the operator action time used in human reliability analysis (HRA). As the performed thermal Hydraulic analysis in CANDU PSA, this thermal Hydraulic analysis in this paper is carried out to demonstrate the models and assurances for PSA and to calculate the operator action time used in HRA. [2]

As shown in Fig. 1 the thermal Hydraulic analysis is conducted to calculate the time for the main parameters following 3 cases.

Case 1: feedwater not available after reactor shutdown

As a result of loss of instrument air the reactor is shutdown. Bubbles are generated in fuel channel after steam generators are empty. Also LRVs are open with continuously increasing HTS pressure. Therefore HTS cooldown should be completed by SDCS or EWS should supply makeup water to steam generators before steam generators are empty. As a result of the thermal Hydraulic analysis, if the operator action is delayed the integrity of HTS is threatened by over pressure of HTS and fuel temperature increase.

Table 1: Sequence of event for case 1

Time (sec)	Sequence of event	Remark
0.0	Event occurs	
46	Reactor shutdown	SDS2 SG low level
51	SG low level alarm	SG level : -2.3m
488	LRV open	
2493	SG empty	
	Continuously increase HTS pressure and fuel temperature	

In the abnormal cooldown operation mode, the HTS is then kept cool by the SDCS or EWS supply feedwater to steam generators until steam generators are empty (about 40 minutes).

Case 2: feedwater available after reactor shutdown, but fails to open MSSVs by operator

The HTS pressure remains steadily until auxiliary feedwater is supplied to steam generators. The pressure of steam generators is increased to the setpoint of MSSV open pressure then kept continuously by MSSVs. However the inventory in steam generators is gradually decreased then the HTS pressure increase slowly.

Table 2: Sequence of event for case 2

Time (sec)	Sequence of event	Remark
0.0	Event occurs	
46	Reactor shutdown	SDS2 SG low level
58	SG low level alarm	SG level : -2.3m
333	SG pressure increase to the setpoint of MSSVs open	Not credit
449	LRV open	
8813	SG empty	
	Continuously increase HTS pressure and fuel temperature	

In the abnormal cooldown operation mode, the HTS is then kept cool by the SDCS or EWS makeup water to the steam generators before steam generators are empty(about 3 hours).

Case 3: feedwater available after reactor shutdown, and success to open MSSVs by operator

The operator should be dispatched to gag the MSSVs open for HTS cooldown by SDCS before steam generators are empty or void in HTS generates. If shutdown cooling system is unavailable following OMSSV action, steam generator makeup from the dousing tank or the EWS is required. As a result of the thermal Hydraulic analysis, if the operator action is delayed the integrity of HTS is threatened by over pressure of HTS and fuel temperature increase.

Table 3: Sequence of event for case 3

Time (sec)	Sequence of event	Remark
0.0	Event occurs	
46	Reactor shutdown	SDS2 SG low level
58	SG low level alarm	SG level : -2.3m
333	SG pressure increase to the setpoint of MSSVs open	Not credit
449	LRV open	
3600	OMSSV	2 MSSVs open
5859	Feedwater empty	
10644	HTS temp. increase to 149℃	ROH average temperature
12107	SG empty	
	Continuously increase HTS pressure and fuel temperature	

In the normal cooldown operation mode, the HTS is then kept cool by the SDCS until ROH temperature excess 149℃(about 2.95 hours) or EWS supply feedwater to steam generators until steam generators are empty(about 3.36 hours).

3. Conclusions

There are 19 events in the event tree of loss of instrument air as shown in Fig. 1. Reactor can be shut down safely after success of SDCS cooldown or secondary heat removal operation in event No. 1, 2, 7, 8, 13 and 14. Residual heat can be removed by ECC and Moderator Heat Sink (MHS) in the situation of pressure tubes contacting calandria tubes after failing SDCS cooldown or secondary heat removal operation. Core damage can occur in event No. 4, 5, 6, 10, 11, 12, 16, 17 and 18 when ECC and MHS are unavailable in the situation of pressure tubes contacting calandria tubes after failing SDCS cooldown or secondary heat removal operation. Event No. 19 represents that the core damage occurs because reactor fails to trip.

REFERENCES

[1] AECL, Probabilistic Safety Assessment - Wolsong NPP 2/3/4, 86-03600-PSA-002 rev.0, 1996.
[2] KHNP, Probabilistic Safety Assessment Wolsong NPP 1, 2011.