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Development of Simplified Shutdown PSA Model for CANDU plant

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1. Introduction

Nuclear reactor operating experience has shown that plants can be subject to a variety of events during shutdown operation that pose potential safety challenges. Because the full scope LPSD PSA models are difficult to develop and utilize, most utilities rely on qualitative methods to ensure safe operation during shutdown. As a part of a National Nuclear Technology Program of Ministry of Science & Technology (MOST), KEPRI is developing a defense-in-depth model (ORION) to monitor risk during the planned outage for CANDU reactors. To complete this qualitative defense-in-depth model, and to add new insight from a risk profile, a simplified probabilistic safety assessment process has been developed and applied to an outage schedule of any CANDU. This approach is described herein briefly, and the result of the example evaluation is presented.

2. Probabilistic Safety Assessment Method During an Outage

2.1 Initiating events during shutdown operation

An analysis for shutdown states addresses concerns that are simultaneous system unavailability during different POSs of an outage, the importance of operator actions to restore functions, and maintenance restrictions to various mitigating and safety systems, while the plant is in a specified shutdown state.

A shutdown PSA can provide insight for outage planning, plant operations and procedures during an outage, outage management practices, and design modifications. In this study, the scope of the shutdown PSA model is a guaranteed shutdown and "drained to header levels" configuration because most maintenance activities are performed within this configuration.

An initiating event during power operation is defined as "whatever causes a scram". However, such a convenient and clear definition of what constitutes an initiating event does not exist for operating during shutdown. An initiating event is defined as any event that requires an automatic or manual plant response in order to maintain the critical safety functions such as the decay heat removal. Four IEs were identified. These events may occur while the reactor is cold, depressurized and drained to the header level.

1) Loss of Shutdown Cooling : Total loss of shutdown cooling is defined as SDC pump failure to move the PHTS(Primary Heat Transfer System) inventory from the ROH (Reactor Outlet Header) to the RIH(Reactor Inlet Header) and/or failure of the SDC heat exchangers to remove heat from the PHTS.
2) Loss of Service Water : Total loss of service water is defined as the absence of any recirculating water (RCW) flow and absence of any RSW flow through the RCW/RSW heat exchangers
3) Loss of Class IV Power: Total loss of class IV is defined as the loss of power to both 13.8 kV class IV buses.
4) PHTS Leaks : PHTS Leaks are defined as the loss of PHTS inventory at a rate that is no higher than the capability of one D2O feed pump which may cause the loss of shutdown cooling

2.2 Accident Sequence Development

In this study, accident scenarios were developed for POS E and F (i.e., drained operation status). In developing the event trees above four IEs, success criteria were decided by T/H analyses. The results of T/H analysis using RELAP/CANDU code are shown in Table 1. If one SG per loop is available, the decay heat removal by thermo-syphoning operation will be success and no core damage occurs as shown in Table 1. Figure 1 shows the loss of SDC event tree for the drained POS.

Table 1. T/H evaluation results for CANDU plant

POS	Number of SG available	Fuel Cladding Temp (K)	Note
POS E	2 per Loop	397	No Core Damage
	1 per Loop	397	No Core Damage
	0	1073	Core Damage @ 14780 sec)

When the PHTS is drained to the header level (i.e. at the POS E & F), the SDC system is used as the primary heat sink and the SG system as the secondary heat sink. This plant configuration is typically required for the SG Tube ECT and PHTS pump seal replacement. When the reactor is in the “drained to headers level” configuration, the major concern in the accident sequence of the all initiators is that the SDC system is unavailable. Under this configuration, the SGs are not automatically established as the secondary heat sink. It is required that the rapid isolation of leak paths and fill up of the PHTS by operator.

Natural circulation can provide effective heat transfer from the fuel to the SGs when only two SGs are available, provided that they are on opposite ends of the reactor.

If neither the SDC nor the SG can be established as a heat sink, the operator can manually initiate ECCS.

In case when the PHTS has been isolated, filled and natural circulation has been established to the SGs, subsequent operator action to feed secondary side using AFW or EWS is required to ensure the long term heat removal.

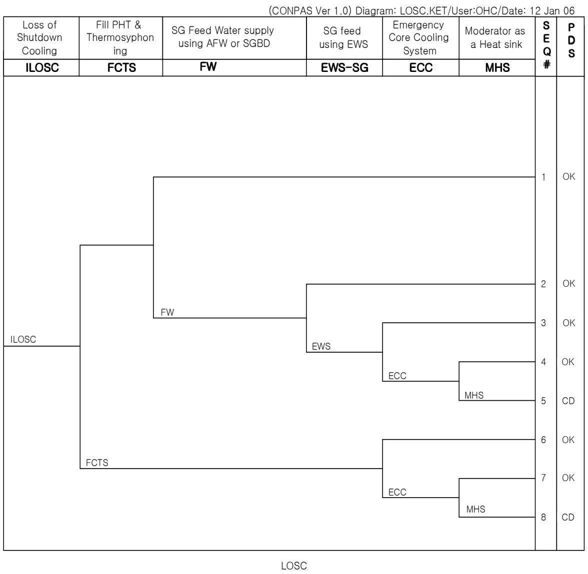

Figure 1. LOSDC Event Tree

2.3 Application

This PSA model was applied for the risk evaluation of an outage. Table 2 shows the outage schedule for any CANDU plant. And figure 2 show the relative risk profile for this schedule. The high risk maintenance activities during an outage can be identified.

Table 2. Outage Schedule for any CANDU Plant

No	Maintenance Activities	October																	November		
		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3
1	SDG # 2 Maint																				
2	SDG # 1 Maint																				
3	D2O feed pump 1,2 Maint																				
4	SG 2,4 ECT																				
5	ECCS P/P Maint.																				
6	Moderator P/P 1 Maint																				
7	Aux feedwater P/P 104 shaft Maint																				
8	Aux feedwater Check V/V 3 Maint																				
9	13.8 Kv/4.16 Kv (Bus A,E) Maint																				
10	13.8 Kv/4.16 Kv (Bus B,F) Maint																				
11	PHT P/P #1,3 seal replace																				
12	PHT P/P #2,4 seal replace																				
13	Condenser Tube ECT																				
14	Main feedwater P/P #1,4 Maint																				

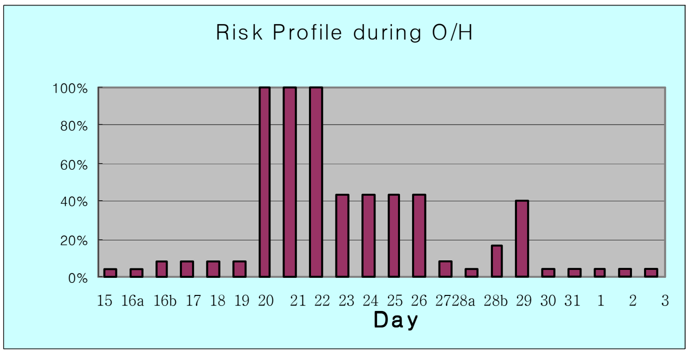

Figure 2. Risk profile for the outage schedule of CANDU plant

3. Conclusions

The simplified PSA model can identify the higher instantaneous risk, with operator actions an important contributor. While defense in depth ensure safe operations throughout the outage, the risk profile can very significantly depending on the alignment of deferent system. The results from the shutdown PSA provide insights into the key operator actions and factors affecting the operators’ response.

This ORION (Outage Risk Indicator of NPP) program which is blended with DID and PSA will be useful to maintain, or reduce, the shutdown risk as shorter outage are implemented.

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