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Risk Effect Evaluation of Helium Injection Line Operability in CANDU Shutdown System

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1. Introduction

Recently, one of the CANDU power plants experienced an internal leakage in one valve (PV1G) among the helium injection valves in the shutdown system(SDS). When the helium injection line was in the unavailable state due to this leakage, a risk evaluation was performed in consideration of the unavailable state of the affected valve(PV1G). This operating experience proved that safe plant operation was possible even though the shutdown system was partially unavailable due to maintenance being required.

2. Risk Evaluation

A CANDU power plant should maintain three flow paths available to inject high pressure helium into the poison injection tank from the helium supply tank. One shutdown system valve leakage caused one poison flow path(PV1G) out of the three flow paths, to enter the limited condition of operation(LCO). The recovery deadline for this LCO condition was the next outage.

Therefore, the safety improvement measures were reviewed including methods to avoid an unavailable state for the entire shutdown system in which another piece of equipment in the system redundancy also becomes unavailable as well as the PV1G leakage.

A channel G/H/J functional test was conducted after PV1G and PV2J were manually closed. Those valves were temporarily closed without using the valve controls in order to offset the system safety degradation because the channel J functional test was not possible due to the internal leakage of PV1G.

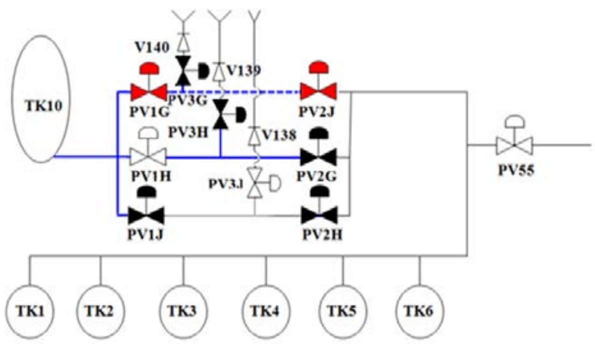

Figure 1. Failed helium injection flow path

2.1. Safety Review

The safety effect was reviewed in order that the reactor trip function of the plant would not be reached within the design concept that used channel combinations of G plus H, G plus J, and H plus J (i.e. 2 of 3 channels) through maintaining PV1H in the open state and PV3H in the closed state during normal operation. PV1H and PV3H should return to service during the channel G and channel H testing.

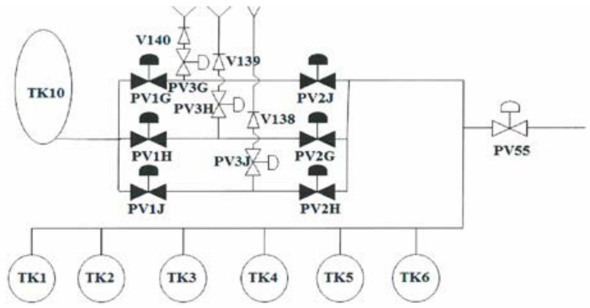

Figure 2. Normal helium injection flow path

2.2. Unavailability Estimation of Configuration Changes

First, the system unavailability was estimated in the normal system operation state in order to calculate the unavailability changes due to the failed flow path state described above. The estimation is described in equation (1), as follows. The shutdown system becomes unavailable if the three flow paths fail. G, H, and J refer to the channel name, and the valve condition is changed from the open state to the closed state or from closed state to the open state, according to the channel actuation direction.

$$G(J+H) + H(G+J) + J(H+G) = GJ + GH + HJ \quad \text{-----(1)}$$

For example, G(J+H) is when channel J or channel H fails after the first flow path (1G-2J) and the second flow path (1H-2G) is unavailable due to the failed channel G. This case has 0.03 system unavailability assuming that the channel failure probability of the shutdown system is 0.1.

Second, the calculation of the system unavailability with one helium injection flow path closed is undertaken using equation (2).

G(J+H) + H + JG = H + JG -------------(2)

For example, valve 1J or 2J becomes unavailable when channel J fails. This failure causes two flow paths to be unavailable if channel G also fails. This case has 0.11 system unavailability if the channel failure probability of the shutdown system is 0.1.

Third, the failure combination is described in equation (3) when PV1H is open with one injection flow path closed due to its failure.

G(J+H) + J(G) + HG = GH + JG ------------- (3)

For example, the first flow path (1G-2J) becomes unavailable when channel G fails. Furthermore, the third flow path (1J-2H) becomes unavailable when channel H also fails. This condition results in the entire system becoming unavailable. This case has 0.02 system unavailability assuming that the channel failure probability of the shutdown system is 0.1.

2.3. Fault Tree Modeling

A risk evaluation model was implemented assuming that one flow path operation is not possible with regard to all nine parameters because the helium injection flow paths should be actuated according to the setpoints of the nine trip variables.[1]

These trip variables are high neutron flux, high neutron flux rate, low core differential pressure, high reactor coolant pressure, low cooling water pressure, low boiler level, low pressurizer level, high containment pressure, and low steam generator feedwater pressure. The unavailable PV1G-PV2J path and the sustained-open condition are reflected in the fault tree model.

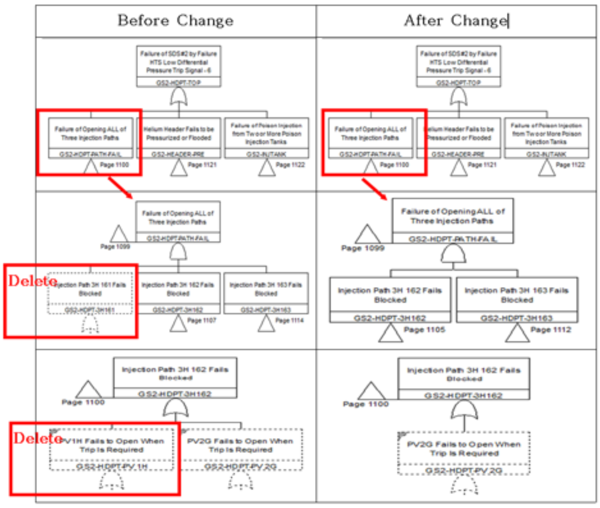

Figure 3. Fault trees indication the configuration changes

2.4. Risk Effect Evaluation

According to the previous CANDU risk analysis [1], the shutdown system (SDS) actuation is activated according to the emergency trip signals for 25 initiating events of the 34 possible initiating events in CANDU power plants. It is analyzed that core damage occurs when the shutdown system fails during an accident. The shutdown system (SDS) becomes unavailable if both SDS number 1 and SDS number 2 fail simultaneously. The portion of the core damage caused by the 25 initiating events is 0.04 percent.

This risk evaluation considers the unavailability of only one of three flow paths for poison injection into the core. According to the evaluation results, the failed state did not cause significant effects on the core damage frequency.

Table 1. Risk evaluation with the configuration changes[2]

State	CDF(/year)	Change(ΔCDF)
Normal state	4.73E-06	-
Failed state	4.73E-06	-

Table 2. Risk portion of SDS compared with the plant CDF

-	CDF(/year)
Plant	4.73E-06
SDS	2.12E-09
SDS portion	0.04%

3. Conclusion

This paper evaluated the risk effects of the unavailable shutdown system (SDS) helium injection line due to its internal leakage in a CANDU plant. This evaluation was conducted considering the condition of the temporally changed system configuration. The result confirmed that the risk change from the failed valve in the helium injection flow path was not significant. This minor risk effect was demonstrated by the relatively small risk portion of the shutdown system in the current probabilistic safety assessment.

In conclusion, the loss of operability of one poison flow path in the SDS does not result in a significant risk change if there are compensatory configuration changes. This analysis contributed to evaluating the plant safety effect related to a major system or equipment operability issue in order to support safe operation of nuclear power plants.

References

[1] CANDU probabilistic safety assessment, KHNP, 2007.
[2] Reliability data of CANDU equipment, 2005.