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Priority Rankings of the System Modifications to Reduce Core Damage Frequency of Wolsong NPP Units 2/3/4

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Abstract

The analysis for priority rankings of the recommendations to reduce the total core damage frequency (CDF) of Wolsong nuclear power plant units 2/3/4 was performed in this paper. In order to derive the recommendations, the sensitivity analysis of CDF on which major contributors effect was performed based on the accident quantification results during Level 1 probabilistic safety assessments (PSA). Priorities were ranked in the way that compares the CDF reduction rate with the efforts required to implement those recommendations using risk matrix.

I. Introduction

A set of integrated safety analysis reports for newly constructed nuclear power plants should be submitted to the regulatory authority for their review of the design safety against severe accidents. According to such a current licensing practice, Level 2 PSA was performed for Wolsong nuclear power plant units 2/3/4. All initiating events caused by internal and external events have been selected, and event trees were developed to identify severe accident sequences. Fault trees were developed to calculate components and systems unavailabilities. CDF was quantified by linking the fault trees into the event trees. Plant damage states (PDS) were developed by grouping the relatively large number of core damage sequences into a smaller set of state or bins, each representing similar plant status after core damage. Containment event trees (CET) were developed to model containment response during severe accident progression. CETs depict various phenomenological processes, containment conditions, and containment failure modes that can occur under severe accident conditions.

As a result of the PSA, an overall appreciation of severe accident behavior was developed, the most likely severe accident sequences that could occur at Wolsong units 2/3/4 were found, a more quantitative understanding of the overall probability of core melt and radioactive material releases were gained, and dominant plant-specific vulnerabilities to severe accident were identified. With these technical insights, the major contributors to core damage were identified, and sensitivity analysis was performed to estimate how each contributor effects on CDF. Finally, the recommendations were derived for enhancement of the plant safety such as reinforcing the plant facilities, and improving the operating procedures that can reduce plant vulnerabilities against severe accidents.

In this paper, the recommendations to improve the safety of Wolsong units 2/3/4 to severe accidents are derived from PSA results, and the priority rankings are performed by comparing CDF reduction rate with the efforts required to implement those recommendations. Section II describes the major contributors to CDF identified during Wolsong 2/3/4 PSA, and sensitivity analysis results of each contributor that effects on total CDF are discussed briefly. In section III, the priority rankings of the recommendations for enhancement of the plant safety are analyzed, and finally, section IV summarizes the conclusion.

II. Major Contributors to CDF and Its Sensitivity Analysis Results

The most important components and factors that contribute dominantly to total CDF are identified based on the accident sequence quantification result. After identification of the major contributors, sensitivity analysis was performed to evaluate how each contributor effects on core damage frequency.

In the internal event analysis, the test interval of shutdown cooling system (SDCS) was identified as an important factor that contributes to total CDF. The current technical specification requires the SDCS to be tested at every one year for SDCS, and this test interval increases the system unavailability. If the test is performed at every one month in stead of one year, it will reduce about 7.8 % of the total CDF. The pneumatic valves, PV-7 and PV-41 of the emergency water supply system (EWS), with relatively higher failure rate (2.679E-3) than that of other similar type valves increase system unavailability. In case of improving the failure rate (1.22E-3) equivalent to other similar type valves, it will reduces about 3.4 % of the total CDF.

In the seismic event analysis, the structural failure of EWS would lead to loss of the EWS pumps and it eventually leads to core damage. If structural integrity of EWS is maintained during earthquake, it will reduces about 11.3 % of total CDF. The structural failure of class III 4.16kV/480V load centers and loss of class III motor control centers (MCCs) contribute dominantly to core damage. Since the MCCs provides power to the Class I and Class II components, it would lead to the loss of Class I and II power after one hour which batteries provide power. In case that group 1 system fails, operator should move to the secondary control area (SCA) and operate group 2 systems manually. If operator fails to perform action, core will be melted down. Protecting the Class III 4.16kV/480V transformers and Class III 480V MCCs in the inverter room against seismic induced structural failure will reduce about 11.0 % of total CDF. In addition, human error contributes to core damage dominantly during seismic event. Human error probability (HEP) is a significant contributor to the total CDF. After an earthquake, operator has a potential for human error in monitoring and appropriate control of the plant. Improvement of operator's reliability coping with seismic event can reduces about 9.2 % of the total CDF.

In the fire event analysis, failure of fire suppression in the reactor building is the most dominant factor that leads to core damage. If fire suppression is succeeded, total CDF will be reduced by 3.0 %. Fire initiated in the gap between service building and turbine building contributes dominantly to core damage. If fire propagation to other essential electrical cables or components can be suppressed by automatic fire suppression system, the total CDF will be reduced by 2.0 %.

In the internal flood event analysis, human error probability contributes dominantly to core damage. If operator performs the action properly to prevent flooding from propagating other rooms in which essential components to CDF are located, the risk due to internal flood will be reduced by 7.6 %. The failure rate of piping expansion joints located in component cooling water heat exchanger room and condenser area are the major contributor to flood PSA. Since these area have several piping expansion joints, the flood frequency in these area is relatively higher than other areas. In this analysis, more or less conservative reliability data for expansion joints obtained from Ontario-hydro database was used. If more realistic data (Oconee PSA data) is used, the total CDF will be reduced by 9.0 %. The major contributors to CDF and CDF reduction rate in case of improving plant vulnerability due to each contributor are summarized in Table 1.

Table 1. The Major Contributors and the CDF Reduction Rate

Events		Major Contributors	Recommendations (Refer Section IV)	CDF Reduction
Internal Events		1. Test interval of SDCS	A	7.8 %
		2. The pneumatic valve failure rate of EWS	B	3.4 %
External Events	Seismic	3. Seismic induced failure of the EWS	C	11.3 %
		4. Failure of the Class III 4.16kV/480V transformer & MCC in inverter room	D	11.0 %
		5. Human error probability	E	9.2 %
	Fire	6. Failure of fire suppression in the reactor building	F	3.0 %
		7. Failure of fire suppression in the gap between service building and turbine building	G	2.0 %
	Internal Flood	8. Operator action to stop flood propagation	H	7.6 %
		9. The Failure rate of expansion joint	I	9.0 %

III. Priority Rankings of Recommendations for Safety Improvements to Severe Accidents

The several plant safety improvements have been recommended based on sensitivity analysis results. The derived recommendations are classified into reinforcement of the vulnerable facilities, establishment of the procedures and operator training, and improvement of component reliability etc. The detailed recommendations are as follows;

A. Reduction of SDCS test interval from one year to one month

B. Upgrading the quality of EWS valves, PV-7 and PV-41, to reduce failure rate about twice

C. Reinforcing the EWS building structure with brace to prevent the collapse during strong earthquake

D. Reinforcing 4.16 kV transformer and MCCs in the inverter room by adding more anchorage between components mount and concrete foundation

E. Establishing the seismic procedures and training operators for the successful interventions of opening MSSVs at MCR and SCA, gag-opening MSSVs at field, and actuating ECCS and EWS at SCA.

F. Installation of fixed automatic fire suppression systems around the pumps located at access area and fuel machine auxiliary room in reactor building or establishing the fire protection program for reactor building in order that operator can extinguish the fire manually

G. Installation of fixed automatic fire suppression system in gap between service building and turbine building

H. Preparing the flood scenario for the flood areas, T-02/T-03 and condenser area, and training operators for proper actions to prevent flooding from propagating into other rooms containing essential components to CDF

I. Collecting the operating experience of piping expansion joints failure for component cooling water heat exchanger room and condenser area, and revising the failure data equivalent to Oconee PSA data, 2.54E-4

Priority rankings for the suggested recommendations are performed in the way that ranks priorities according to the required effort to reduce the total CDF using risk matrix as shown in Figure 1. In the estimation of the efforts to reduce CDF, three factors have been considered such as the required time of implementation, executability, and cost. Those factors were determined based on engineering judgement. The required time of implementation was grouped in two categories, a short term which was ranked as "low", and a long term "high". Executability was defined as two categories, an easy implementation by construction staff which was ranked as "low", and a systematic review required by design engineer "high". Cost was classified on the basis of man-month needed for implementation, less than one man-month which was ranked as "low", and more than one man-month "high". In the same way, the risk reduction rate was also grouped in two categories, less than 5 % which was ranked as "low", and more than 5 % "high". The priorities were classified into four groups, i.e., critical(I), important(II), attentionable(III), and negligible(IV). The priority ranking results are summarized in Table 2.

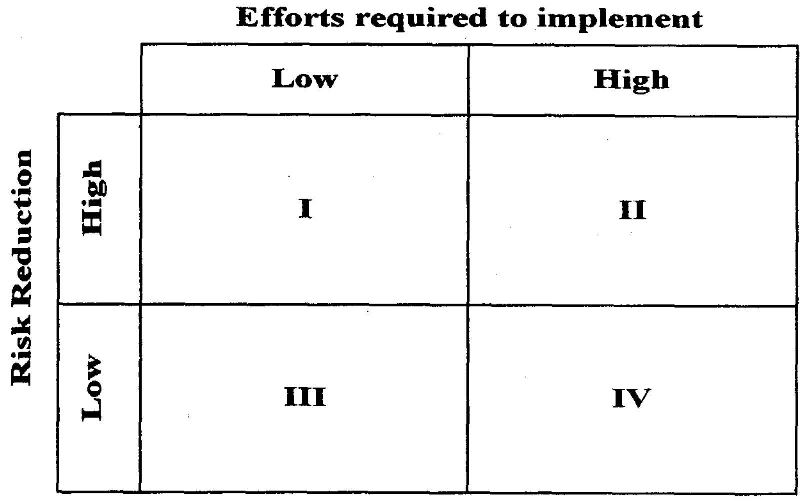

Figure 1. Risk Matrix for Priority Rankings

Table 2. The Priority Rankings of Recommendations

Priorities	Definitions	Recommendations	Total CDF Reduction
I	Critical	A, C, D, E, H	46.9%
II	Important	F, G	5.0%
III	Attentionable	I	9.0%
IV	Negligible	B	3.4%

IV. Conclusion

The result of PSA for Wolsong NPP units 2/3/4 pointed out that CANDU plants have design features that is vulnerable to external event. Based on the accident quantification results, major contributors to the total CDF are identified. Also, recommendations were concluded from sensitivity analysis of CDF on which how each contributor effects to reduce total CDF due to severe accidents. As a result of priority rankings, five of the nine recommendations are classified into critical (priority I), and the rest are classified into other groups. About 46.9 % of total CDF is reduced provided that recommendations classified into Critical(Priority I) are implemented. on the other hand, 64.3 % of total CDF is reduced if all of the recommendations are implemented.

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