Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2011

Audit of ECCS Availability for CANDU Reactors with an extended O/H interval

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1. Introduction

KINS conducts regulatory periodic inspections of the safety and performance of each nuclear installation during the planned outage every 20 months, pursuant to the Atomic Energy Act. For CANDU reactors, planned outage or overhaul (O/H) have been performed every 15 months. KHNP has been making efforts to extend the O/H intervals of CANDU reactors into 20 months since 2001. Low ECCS availability is one of the regulatory pending issues in the related licensing.

2. O/H Interval Extension for Wolsong NPP 2/3/4

2.1 Requirement of ECC Availability

The Emergency Core Cooling (ECC) System is a special safety system for CANDU reactors. It will act following a Loss of Coolant Accident (LOCA) to refill the Primary Heat Transport (PHT) System and to remove residual and decay heat from the reactor core, thus, limiting fuel damage.

The Section 3.4.1 of AECB Regulatory Document R-9 [1] stipulates that the ECCS shall be designed such that the fraction of time for which it is not available can be demonstrated to be less than 10^{-3} years per year, and the system shall be considered available only if it can be demonstrated to meet all the minimum allowable performance standards….

2.2 Current License Base of ECC Availability

The Analysis Report [2] for ECC availability is a licensing document of Wolsong NPP 2/3/4. The scope of the report includes the determination from the fault tree analysis of ECC unavailability for the following events:

a) ECC fails to supply emergency core cooling on demand, following a LOCA at full power;
b) ECC fails to provide sufficient cooling during the first 24 hours of long-term low pressure operation.

The fault tree model for the ECC dormant failure contains a detailed analysis of ECC cooling water supply to the heat transport system (HTS) as well as the ECC related functions of steam generator crash cooldown and heat transport system loop isolation. Failure rates and characteristic times (e.g., MTTR) have been taken from Chapter 7 Risk Assessment Data - Darlington NGS A Risk Assessment (DARA) study.

The largest contributors are the check valves (3432-PV33, PV48), supplying the failed HTS loop in the list of minimal cutsets for ECC dormant failure. These two singletons account for approximately 28% of the top event unavailability together. The next largest cutset, starting failure of both ECC pump motors, is significantly smaller at 3.2%. The resulting model represents dormant ECC unavailability with a total unavailability of 8.05E-04.

The ECC check valves 3432-PV33/34/47/48 were considered to be remotely tested every 3 months in the analysis. Actually, these valves have been tested only during O/H. Now, the license amendment for O/H interval extension of Wolsong NPP 2/3/4 is reviewed by KINS.

3. Audit of ECC Availability

3.1 Audit of Rebuilt ECC Availability Model

In the regulatory review of the license amendment for O/H interval extension, rebuilding a fault tree model of ECC availability for Wolsong NPP 2/3/4 is required. The rebuilt model was verified by comparing with the Analysis Report [2].

Table 1 shows the predicted ECC unavailability for some test and maintenance plans using the rebuilt fault trees and the original component reliability data. The analysis results given in Table I do not show that the O/H extension meets the availability requirement.

Table I: Predicted unavailability for dormant ECC based on the original model and data

Test Interval	3 Months	15 Months	20 Months
O/H Interval	15 months	15 months	20 months
Prob. (C/V FO)*	1E-4	5E-4	6.67E-4
ECCS Unavail.**	8.1217E-4	1.6124E-3	1.9895E-3

* fail-to-open probability for check valves (PV33/34/47/48)
** calculated with a probability truncation limit of 1E-10

3.2 Newly-proposed Data for D_2O Check Valves

KHNP insists that the original data for the probability that the check valves (3432-PV33/34/47/48) fail to open is overestimated. Table II shows some typical generic data for check valve's failure to open. The probability from EIReDA [3], European data bank, is considered in License amendment for O/H interval extension of Wolsong NPP 2/3/4.

Table II: Probability that a check valve fails to open

Generic Database	Issued in	Prob. of demand fail.
EPRI URD	1995.12	2.0E-4
NUREG/CR-4639	1994.9	5.3E-4 (median)
NUREG/CR-6928	2007.2	1.2E-5
EIReDA	1998	1.5E-5

In the review of the amendment, KINS judged not only that the probability from EIReDA is valid for the ECC check valves but also that the relationship between failure probability and test interval must be considered.

The relationship between a failure-on-demand model and a failure-in-time model (assuming a constant failure rate) can easily be seen mathematically. If it is necessary to obtain a new probability of failure on demand, p_1, for a new test period τ_1, the following relationships must be considered. The new demand probability is [4]

$$p_1 = 1 - (1-p)^{\tau_1/\tau} \quad (1)$$

In this study, it is assumed that the EIReDA value of Table II is valid just for the 3 month test interval and the data for the check valve (3432-PV33/34/47/48) shown in Table III can be used in this audit calculation. Table III shows the predicted ECC unavailability for the selected test and maintenance plans using the rebuilt fault trees and the newly-proposed data. The analysis results of Table III show that the O/H extension meets the availability requirement.

Table III: Predicted unavailability for dormant ECC based on the original model and newly-proposed data

Test Interval	3 Months	15 Months	20 Months
O/H Interval	15 months	15 months	20 months
Prob. (C/V FO)	1.5E-5	7.5E-5	1E-4
ECCS Unavail.*	6.4216E-4	7.6216E-4	8.5509E-4**

* calculated with a probability truncation limit of 1E-10
** reported unavailability for dormant ECC with 20-month OH

3.3 Exact Quantification of ECC-D without TE & AE

The quantification of NPP Probabilistic Safety Assessment (PSA) always has the following two limitations: (1) Truncation Errors (TEs) in deleting low-probability cut sets and (2) Approximation Errors (AEs) in quantifying Minimal Cut Sets (MCSs). A practical method to exactly quantify PSA was developed [5].

Fig. 1 is the TE evaluation of the license amendment case based on the exact method.

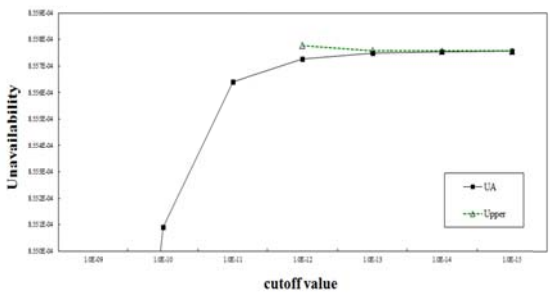

Fig. 1. Unavailability with a series of cutoff values

Fig. 2 is the MCS quantification by Semi-SDP for TL=1E-15 and the AE evaluation of the license amendment case based on the exact method [5].

Table IV shows an exact unavailability for dormant ECC and its TE/AE predicted by the exact technique. Table V shows quantification errors (TE/AE) in the MCS quantification result with TL=1E-10 (i.e., 8.5509E-4 of Table III). It shows that the value of 8.5509E-4 is also overestimated.

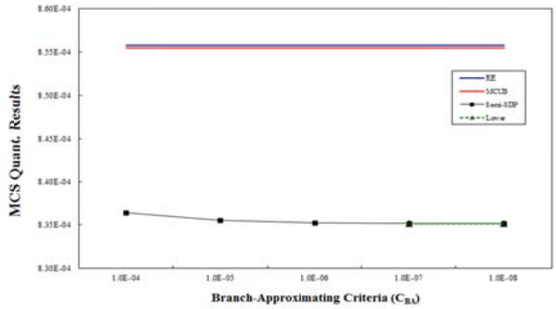

Fig. 2. MCS quantification by Semi-SDP for TL=1E-15

Table IV: Exact unavailability for dormant ECC

Exact ECC Unavailability	Truncation Error	Approximation Error
8.3515E-4	~ 9.3E-5 %	~ 1.4E-6 %

Table V: Evaluation of quantification errors

Reported Unavailability	Reported / exact	Truncation Error	Approximation Error
8.5509E-4	102.388%	~ 0.078%	> 2.401%

4. Conclusions

This study is to show a regulatory audit calculation to confirm if the license amendment for O/H interval extension of Wolsong NPP 2/3/4 is appropriate in the light of the ECC unavailability target of 10^{-3}. By rebuilding a valid ECCS model and quantifying it without truncation errors and approximation errors, the effect of O/H interval extension on ECCS availability is evaluated. This study will help KINS make a regulatory decision on the license amendment.

REFERENCES

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[4] NRC, PRA Procedures Guide, NUREG/CR-2300, 1983.

[5] J. Choi, Quantifying Truncation Errors And Approximation Errors in PSA, PSA 2011, Wilmington, March 13-17, 2011.