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Failure Probabilities and MR Performance Criteria versus variation in Surveillance Interval

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1. Introduction

As a part of efforts to develop a fleet-wide Maintenance Rule program of Korea Hydro & Nuclear Power Co. (KHNP), we are developing a CANDU program. Three CANDU reactors were connected to the grid between July 1997 and October 1999. Initially, the same design and Technical Specifications were applied. One reactor (Unit A) has been operated by Plant 1 organization while the other two reactors (Units B and C) have been operated by a different organization of Plant 2. Each organization has different operating procedures and surveillance intervals, which influence the component reliabilities and Maintenance Rule performance criteria according to the variation in surveillance test intervals (STIs). This paper evaluates the influence of different surveillance test intervals on the Maintenance Rule program and component failure probability and recommends some considerations to prevent these problems.

2. Methods and Results

In this section the influence of the surveillance test interval on the Maintenance Rule Performance Criteria (PC) is described. The data needed for setting Reliability Performance Criteria (RPC) include the specific component failure rates from Probabilistic Safety Assessment (PSA) data, the number of operating demands, the operating time during three years and the number of components in the train.

2.1 Technical Specification requirement and expected number of failures

These CANDU units share the same Design Manuals, Technical Specifications and Final Safety Analysis Reports (FSARs).

Technical Specifications consist of the Limited Condition of Operation (LCO) and surveillance requirements.

Surveillance tests are required for the standby safety systems and supporting components. Their intervals are specified as 12hrs, 24hrs, weekly, monthly, quarterly, yearly, refueling cycle, etc. These intervals constitute exclusive demands for standby safety systems, as they are not operating in the normal operation mode.

Surveillance test requirements in the Technical Specifications for the same system components of these CANDU reactors are basically the same except for the cases where revisions have been applied. However, the actual surveillance test intervals are different, especially with respect to monthly tests. The procedures for Unit A monthly tests entail a four week interval while the interval for the other two units is specified as 31 days. As a result of this difference, the annual number of monthly tests for Unit A is 13 whereas monthly tests for the other two units are carried out 12 times per year. Table 1 compares the Emergency Core Cooling (ECC) pump test intervals between the plants.

Table1. ECC pump monthly test intervals and operating demands per 3 years, failure rate

	Unit A	Units B & C
ECC pump test interval in Technical specification	31 days	31 days
ECC pump test interval in test procedure	4 weeks	31 days
ECC pump demand/ 3yrs	39	36
ECC pump demand-on-failure probability (Pd)	2.03E-03	2.03E-03

The expected number of failures (λT) is determined by the failure rate (λ) and the number of exposures (T). Exposures consist of the demand (d) for standby components and the running time (t) for normal operating components. Failure rate includes demand-on-failure probability (Pd) for fail-to-start mode and running failure rate (λr) for fail-to-run mode.

$$\lambda T = \lambda r \times t + Pd \times d \qquad (1)$$

Failure rate (λ) depends on the type of component. The basic event probability of PSA is the source of failure rate. The expected number of failures is the function of exposure (T) when the failure rate is constant in the case of using the same components. [2]

2.2 Maintenance Rule Performance Criteria

In the KHNP program, the EPRI methodology is used to set the performance criteria. EPRI documents use Poisson or Binomial distributions for estimating the allowable number of failures from the expected number of failures.

Maintenance Rule Criteria are set by estimation of the allowable number of failures from the expected number of failures. Performance Criteria are a function of the number of demands and failure probability. [1]

If r failures are experienced in n tests, the best estimation of the failure-on-demand probability, P, is P=r/n, However, some SSCs covered by the MR are tested much less frequently than a quarterly rate. It is very difficult to estimate the allowable number of failures in the case of small exposure. [2]

EPRI Technical Bulletin 96-11-01 'Monitoring Reliability for the Maintenance Rule' describes the process and its technical basis for establishing performance criteria for standby components. [2]

EPRI Technical Bulletin 97-3-01 describes the technical basis of selecting performance criteria for continuously operated SSCs and combining runtime failures and standby failures. [2]

The chance of observing zero, one, two, or three failures can be calculated using a Poisson distribution, and the results are used to select a performance criterion that gives an acceptably small probability of accidentally exceeding the criterion. The chance of observing zero, one, or two failures can be calculated using the PSA input value, and the expected number of legitimate demands. [2]

P(n) is the probability of observing n failures, when the expected number of failures is λT during the total period of observation of T component years, for a process that has an average rate of occurrence of λ failures per one year. [2] Figure 1 shows the relation between the expected number of failures (λT) and the probability of n failures with a Poisson distribution (Eq. 2).

$$P(n) = e^{-\lambda T} \times (\lambda T)^n / n! \qquad (2)$$

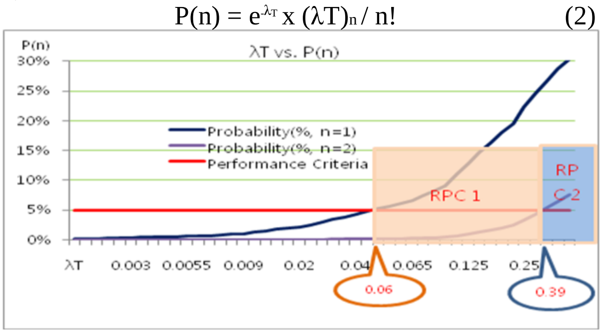

Figure1. Expected number of failures (λT, 0.001~0.5) vs. Probability of observing n failures P(n)

Table2. Expected number of failures and Maintenance Rule RPC for ECC pump train

	Unit A	Unit B & C
Expected number of failures/ 3 years (λT)	0.440	0.381
Maintenance Rule RPC	2	1

KHNP sets Performance Criteria at 5% of the probabilities of n failure. If the failure probability of n=1 exceeds 5% ($\lambda T \geq 0.06$), then the performance criterion is set at 1 failure. When the probability of n=2 is greater than 5% ($\lambda T \geq 0.39$), the criterion is set at 2 failures.

2.3 Variation of surveillance test intervals and influence on Maintenance Rule Performance Criteria

For the present analysis, surveillance test procedures and the failure history during three years for the ECC pump were reviewed. Table 1 indicates that the ECC pump in Unit A is tested more frequently than those in Units B and C.

The expected number of failures for the Unit A ECC pump per three years is higher than that of Units B and C respectively, because the number of tests (demands) for Unit A is respectively greater than that of Units B and C.

The Maintenance Rule Performance Criterion of Unit A ECC pump trains is set at 2 failures/3years. One more failure is allowed than the Performance Criteria of Units B and C for the ECC pump trains.

During the most recent three year period, maintenance reports for the ECC system pump trains were reviewed, and one report was evaluated as a Functional Failure. However, there was no evidence of that more demands result in more failures.

Table3. ECC pump train Maintenance Rule RPC and actual performance

	Unit A	Unit B	Unit C
ECC pump Maintenance Rule Functional Failure	0	0	1

3. Conclusions

Three CANDU reactors were built with the same design and technical specifications. However, they have been operated by different organizations. These organizations have applied different test intervals for plant procedures, resulting in variation in the demands for components, and the expected number of failures in a given period. This also influenced the Maintenance Rule Performance Criteria. More failures are allowed in the case of larger Performance Criteria. On the other hand, components operated more frequently than the Technical Specification requirements have higher probability of failure than rarely operated components as a result of increased demand. Although there is no clear indication that greater demand results in more actual failures, the probability of failure will be increased by more frequent tests. Therefore, surveillance test intervals should be carefully aligned with Technical Specification requirements by comparing the test practices between plants having the same design.

REFERENCES

[1] Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants, NUMARC 93-01 *Revision 3*, NEI, July 2000.

[2] Insights From EPRI Maintenance Rule User Group – Volume 2, EPRI, December 2002