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Statistical Analysis for Piping Aging Trend with OPDE Database

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1. Introduction

The purpose of this study is to perform a significance test for an aging trend of a PWR piping with the OPDE (OECD/NEA Piping Failure Data Exchange) Database. A qualitative analysis for a piping aging trend with the OPDE DB was performed when the JRC (Joint Research Center) Network on "Incorporating Ageing Effects into PSA" was launched to start discussions on aging issues in relation to incorporating the aging effects into PSA tools and to come to some consensus on the objectives and work packages of the Network [1-2].

In this study, a goodness-of-fit test and a Laplace test were applied to confirm an aging trend in a PWR piping based on tests of a hypothesis.

2. Aging Trend of PWR Piping

For a qualitative analysis for a piping aging trend, the plant operation starting dates of 212 PWR plants are moved to an identical time point, Jan. 1, 1970. Each plant is divided into seven groups by every five years of each plant's operation years and piping leak frequencies of each group were calculate by a piping diameter.

In this study, we selected piping leaks that occurred in 30~35 year aged plants, since it was difficult to establish an aging trend with the previous method by which young plants and old plants were mixed. Piping leak frequencies in each group were calculated with the selected data from 30~35 year aged plants.

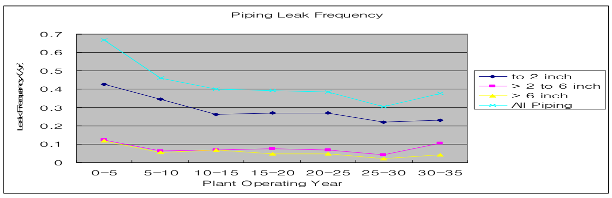

Fig. 1. Piping Leak Frequency from 30~35 Year Aged PWRs

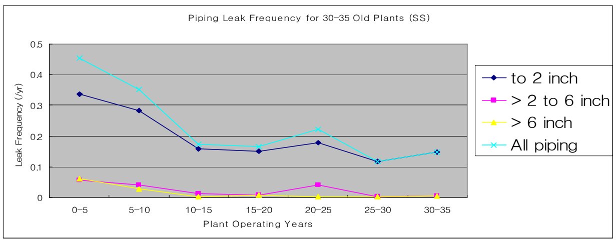

Fig. 2. Piping Leak Frequency from 30~35 Year Aged PWRs (Stainless Steel Piping)

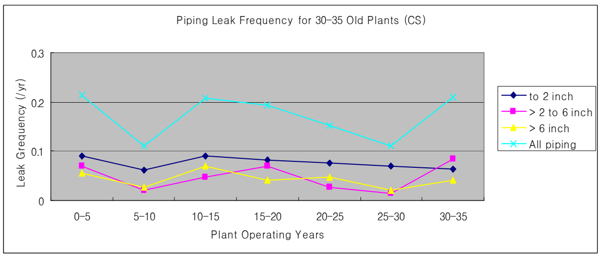

Fig. 3. Piping Leak Frequency from 30~35 Year Aged PWRs (Carbon Steel Piping)

Fig. 1 reveals that the piping leak frequency during the first five years of a plant operation is higher than the others. It may result from an inexpertness of an early plant operation, design deficiencies and a maintenance improvement. Fig. 2 seems to be similar to the shape of Fig. 1 and Fig. 3 has a little bit different shape from Fig.s 1 and 2.

3. Statistical Analysis for Piping Aging Trend

We applied two kinds of statistical analyses such as a goodness-of-fit test and a Laplace test for a significance test of a piping aging trend. They have already been applied for an aging trend test in nuclear fields [3].

3.1 Goodness-of-Fit Test (Chi-square Test)

A goodness-of-fit test is to see how much the observed counts differ from the expected ones. If the difference is small, the counts are consistent with a null hypothesis Ho. Null and alternative hypotheses are as follows;

- H_O: λ is same for all aged year groups
- H_A: λ is not same for all aged year groups

A goodness-of-fit test between observed and expected frequencies is based on a quantity

$$X^2 = \sum_j (n_j - e_j)^2 / e_j , \qquad (1)$$

Where, n_j is the number of observed leak counts and e_j is the number of expected counts. Under the Ho, the test statistic X^2 is approximated by the chi-squared distribution. If p-value, $P(X^2 > \chi^2)$ is less than 0.05, Ho is rejected at a 5% significance level. In this study, we excluded the data during the first five years plant operation period since a plant operation during this period is not stabilized to perform the goodness-of fit test with the reduced data. Table 1, the test result shows that no group by a piping diameter has enough evidence to reject H_O.

Although the goodness-of-fit test has been applied to test a component aging trend, it is not a good test for ordinal variables. With the test, an increasing (or decreasing) trend can not be identified.

3.2 Laplace Test

Laplace test is good for the identification of an increasing (or decreasing) trend of ordinal variables. Null and alternative hypotheses are as follows;

- H_O: No trend (λ is constant)
- H_A: Increasing (or decreasing) trend

Test statistic *U* is as follows;

$$U = -\frac{\overline{T} - \frac{L}{2}}{L\sqrt{\frac{1}{12n}}} \quad (2)$$

where, n events occur at successive times $T_1, T_2, \ldots, T_n$ during a time interval [0, L] and the mean of the failure times $\overline{T} = \sum_i (T_i/n)$. If two types of p-values, $P(U \geq u)$ when u is positive and $P(U \leq u)$, when u is negative are less than 0.05, Ho is rejected at a 5% significance level.

With the Laplace test, more of the times will fall above L/2, positive values of the difference indicate an increasing trend. It is good for detecting a wide variety of monotonic increasing or decreasing alternatives. Table 2, the test result shows that two groups in the case of all kinds of materials and three groups in the case of stainless steel have decreasing trends.

4. Conclusion

We performed two kinds of significance tests to identify a piping aging trend of 30~35 year old PWRs with the OPDE database. With a chi-squared test, it is difficult to establish an increasing (or decreasing) trend though it has been applied for an aging trend analysis. There are decreasing trends in some cases of all kinds of material pipings and stainless steel piping by using a Laplace test. This result could be the result of an improvement for a piping maintenance, inspection, and replacement

REFERENCES

[1] Sun Yeong Choi et al., Aging Trend about Piping from OPDE Database, Proceeding of KNS Conference, 2006 .
[2] JRC, Proceedings of the kick off meeting JRC Network Incorporating Ageing Effects into PSA Applications, Oct. 2004
[3] NUREG/CR-6823, Handbook of Parameter Estimation for PRA, U.S.NRC, 2002.

Table 1. Result of Goodness-of-Fit Test

Piping Group		5-10	10-15	15-20	20-25	25-30	30-35	X^2	P-value
All piping	n_j	67	58	57	56	44	18	4.80	4.4E-01
	e_j	56.30	56.30	56.30	56.30	56.30	18.52		
	$(n_j - e_j)^2/e_j$	2.04	5.2E-02	8.8E-03	1.6E-03	2.69	1.5E-02		
to 2 inch	n_j	50	38	39	39	32	11	4.61	4.6E-01
	e_j	39.22	39.22	39.22	39.22	39.22	12.90		
	$(n_j - e_j)^2/e_j$	2.96	3.8E-02	1.2E-03	1.2E-03	1.32	2.8E-01		
> 2 to 6 inch	n_j	9	10	11	10	6	5	2.71	7.5E-01
	e_j	9.57	9.57	9.57	9.57	9.57	3.15		
	$(n_j - e_j)^2/e_j$	3.4E-02	1.9E-02	2.1E-01	1.9E-02	1.33	1.09		
> 6 inch	n_j	8	10	7	7	3	2	3.78	5.8E-01
	e_j	6.94	6.94	6.94	6.94	6.94	2.23		
	$(n_j - e_j)^2/e_j$	1.6E-01	1.35	4.6E-04	4.6E-04	2.24	3.5E-02		

Table 2. Result of Laplace Test

	Piping Group	L	n	Sum (T)	Mean(T)	U	P-value
All Kinds of Materials	All piping	25	281	3278	11.665	-1.938	2.63E-02
	to 2 inch	25	197	2287	11.609	-1.733	4.16E-02
	> 2 to 6 inch	25	46	544	11.826	-0.633	2.63E-01
	> 6 inch	25	35	375	10.714	-1.464	7.16E-02
Stainless Steel	All piping	25	148	1545	10.439	-3.474	2.56E-04
	to 2 inch	25	128	1377	10.758	-2.731	3.16E-03
	> 2 to 6 inch	25	15	146	9.733	-1.485	6.88E-02
	> 6 inch	25	5	21	4.200	-2.572	5.06E-03
Carbon Steel	All piping	25	112	1357	12.116	-0.563	2.87E-01
	to 2 inch	25	55	682	12.400	-0.103	4.59E-01
	> 2 to 6 inch	25	26	298	11.462	-0.734	2.32E-01
	> 6 inch	25	30	354	11.800	-0.531	2.98E-01