A Study on Data Analysis and Reliability Model by Considering Aging

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Abstract

Several studies on a reliability and data analysis have been performed at the Korea Atomic Energy Research Institute (KAERI). Since the late 1990s, a component reliability database and a transient event database for Korean Nuclear Power Plants (NPP) have been developed. Also a Common Cause Failure (CCF) database and a piping failure database have been established by participating in multi-national cooperation research such as the International CCF Data Exchange (ICDE) and OECD Piping Failure Data Exchange (OPDE). With those databases, trends of some safety related components that have high failure rates were analyzed and a statistical analysis of a piping leak trend was investigated. For a reliability model, a Markov model for an Emergency Diesel Generator (EDG) unavailability was developed.

1. Introduction

Korea has one of the most dynamic nuclear power programs in the world. The first Nuclear Power Plant (NPP) began its commercial operation in 1978. To date, 20 units are in operation providing about 40% of the electricity demand in Korea. Four units scheduled to be built by 2012 are under construction. By the time, a total of 24 units will be operating in Korea. Since operating nuclear power plants are subject to deterioration due to an aging, an appropriate aging management program, like a periodic safety review (PSR), has been proposed and actively performed at the utilities. Based on the safety review results, a plant lifetime could be extended by the unit of 10 years at a time at the end of the design life. Accordingly, there is considerable interest in a component aging analysis and various researches related a component aging has been performed.

The Nuclear Safety Research (NSR) department at the Korea Atomic Energy Research Institute (KAERI) has charge of the research on the safety of Nuclear Power Plants (NPP). In the NSR department, there are the Integrated Risk Assessment Center (IRAC) which performs the Probabilistic Safety Assessment (PSA) and its application fields and the Nuclear Material Research Center (NMRC) which investigates material and failure mechanisms. They have performed several researches related to a component aging from various angles.

The purpose of this paper is to introduce the researches performed in the IRAC of KAERI. The development of a component reliability database is described in section 2. Section 3 and 4 present component failure trend Analyses and a reliability model for Emergency Diesel Generators (EDG) respectively. Finally, conclusions and discussions are presented in section 5.

2. Component Reliability Component Database (KIND)

KAERI has developed an integrated reliability database for some Korean Pressurized Water Plants (PWR) which is called the KIND (Korean Information System for Nuclear Reliability Data) since 1998 for PSAs and Risk Informed Regulation & Applications (RIR&A) [1-2]. The KIND includes a component reliability database and a plant transient event database. Also a Common Cause Failure (CCF) database and a piping failure database have been established by participating in multi-national cooperation research such as the International CCF Data Exchange (ICDE) and OECD Piping Failure Data Exchange (OPDE). In this section, we focus on the component reliability database. In Korea, all the NPPs have changed their recording method related to internal plant failure reports, maintenance records, and plant logs from handwriting to computerization since 2003. Therefore the KHNP (Korea Hydro & Nuclear Power Company) developed the PRinS (Plant Reliability Data Information System) for web based computerized data resources based on the framework and data analysis method of the KIND. At the early stage of the development of the KIND, we concentrated on the construction of the database framework and the systematization of the data collection/analysis. We have issued a guideline which provides a standardized method for a data collection/analysis. We have also designed a database structure and made a database management S/W to input and retrieve data efficiently. Figure1 shows the procedure of obtaining reliability results and an example of a failure data input. We have collected the raw data such as internal plant failure reports and plant logs etc. Then, we input the values for the essential input items of KIND through a data analysis [3-6].

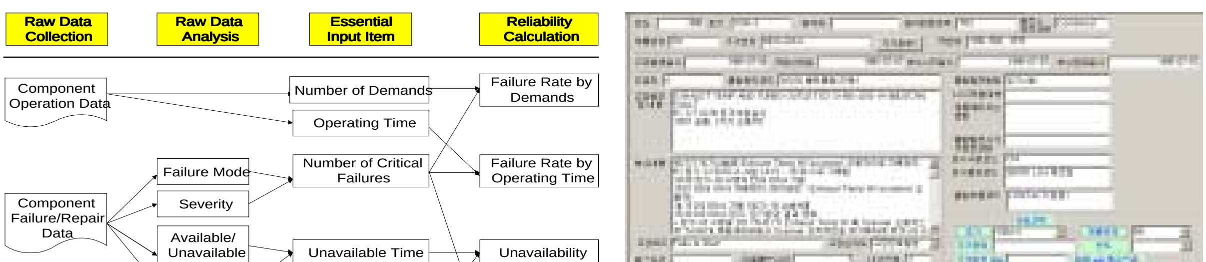


Figure 1. Procedure of Reliability Data and Example of Input of Failure Data

There are several types of data sources for component failures and maintenances. However, the records before 2000 were sometimes too simple to understand in detail. For example, it is difficult to decide whether a component failure occurs at the demand for an operation or during a run time. Also it is not clear whether a component is available right after a failure and/or during a repair time.

To consider the database from an aging aspect, the KIND and PRinS are not sufficient for an aging analysis yet. The first reason is that we did not consider the importance of a component aging at the database development stage. And the second reason is that there are few descriptions about an aging for a failure and maintenance description for raw data though there is a term, ‘wearing’ in the list of component failure cause codes. For an aging PSA, the component reliability database should add more input fields related to a component aging and plant operators need to elaborate on a failure cause in Korea.

3. Component Failure Trend Analysis

With the component reliability data of KIND, we evaluated the components and their failure modes that have high-ranking failure rates among the major safety related rotating components from the first plant operation date to 1998 and 2000 for Yonggwang (YGN) 3,4 and Ulchin (UCN) 3,4 respectively. Then we performed the trend analysis for the fail to start mode of the EDGs and the fail to run mode of the chillers which have high-ranking failure rates in the previous section [7].

Figure 2 shows that the total failure rate of the EDG (Total) is a little bit constant even though it is higher than the generic data (GDB). The failure rate of the AAC DG of the YGN 3, 4 plants shows a trend that it is very high at an early operation stage and then decreases gradually. Figure 3 shows the failure trends of motor driven pumps in YGN 3, 4 and UCN 3, 4. From the failure trend results, we can estimate that all the failure rates are stabilized gradually as time goes even though they show various shapes at an early operation time. Recently, another researches revealed operator analyzed similar trend analyses with a component failure data up to 2005 in the YGN 3 and 4 [8]. The result shows the same shape which is stabilized gradually as time passes.

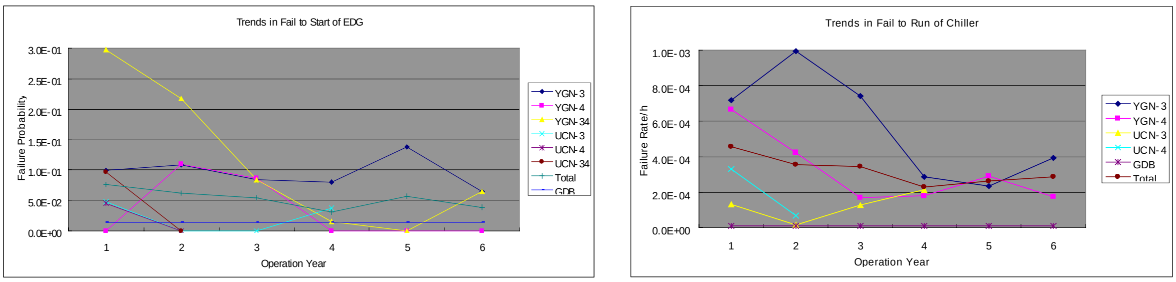


Figure 2. Failure Trends for the EDGs and Chillers in YGN 3, 4 and UCN 3, 4

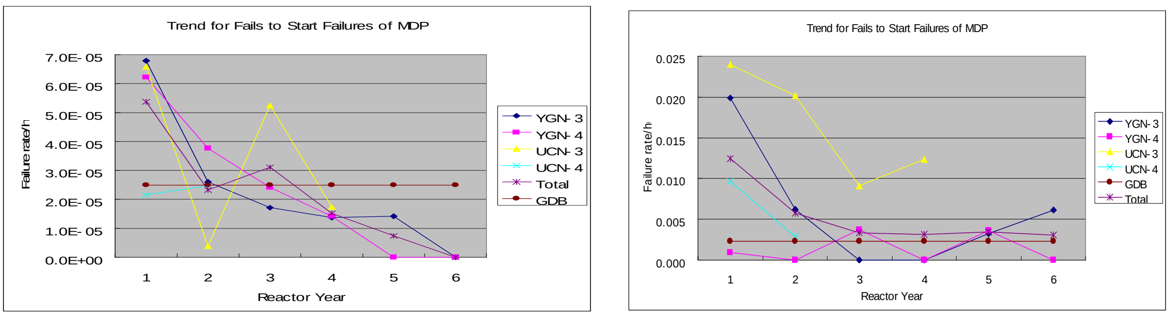


Figure 3. Failure Trends for the Motor Driven Pumps in YGN 3, 4 and UCN 3, 4

In addition to the trend analysis of active component failures, we performed a significance test for an aging trend of a PWR piping with the OPDE database [9-10]. A qualitative analysis for a piping aging trend with the OPDE DB was performed and subsequently a Laplace test was applied to confirm an aging trend in a PWR piping based on tests of a hypothesis. Piping leak frequencies in each group were calculated with the selected data from 30~35 year aged plants. Figure 4 reveals that in the case of the stainless steel piping, the piping leak frequency during the first five years of a plant operation is higher than the others. It may result from inexperience of an early plant operation, design deficiencies and a maintenance improvement. However the graph of the carbon steel piping has a little bit different shape from that of the stainless steel one.

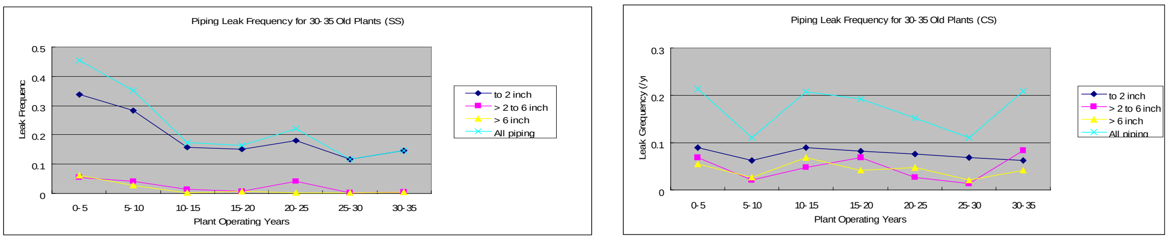


Figure 4. Trends of the Piping Leaks from 30~35 Year Aged PWRs

The Laplace test is good for the identification of an increasing (or decreasing) trend of ordinal variables. Null and alternative hypotheses are 'No trend (λ is constant)' and 'Increasing (or decreasing) trend' respectively. And a test statistic *U* is as follows;

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

where, n events occur at successive times T_1, T_2, …, 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, the null hypothesis 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.

The test result shows that three groups in the case of the stainless steel piping have decreasing trends in Table 1.

Table 1. Result of Laplace Test with Piping Leak Data

	Piping Group	L	n	Sum (T)	Mean(T)	U	P-value
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

4. Reliability Modeling

In the IRAC of KAERI, several system/component reliability modeling have been performed besides the Fault Tree Analysis (FTA). One of them is a Markov model for EDGs. The static models like FTA have been widely used in a system reliability analysis since it is easy to handle. The static model is based on the average unavailability of components over the time period. However, most systems in NPPs are not static, but dynamic in nature, hence, the static models have limitations in evaluating the reliability and/or availability of these systems exactly. The use of a dynamic model enables us to overcome the limitations mentioned above. One of the most commonly used dynamic models is a Markov model. We interpreted the Markov model as a kind of causal loop diagram. That is, the state of the Markov model matches the variables of a causal loop diagram and the transition of the Markov model is regarded as a relationship between the variables [11].

To calculate the reliability of an EDG, failures are investigated from the plant logs and trouble reports issued by the YGN 3 NPP dated from 1995 to 1997. We referred to generic data from NUREG/CR-4810 for the fraction of a starting failure by a demand shock since the starting failure data was not classified into two types of a failure, by a demand shock and during a standby time. The running failure rate is also from NUREG/CR-2989 since it is difficult to estimate the running failure rate with the monthly test data. The beta-factor model is applied to a CCF model in this paper and the value of the beta-factor comes from EPRI data. Figure 5 shows the dynamic unavailability of EDG-A and EDG-B of YGN 3.

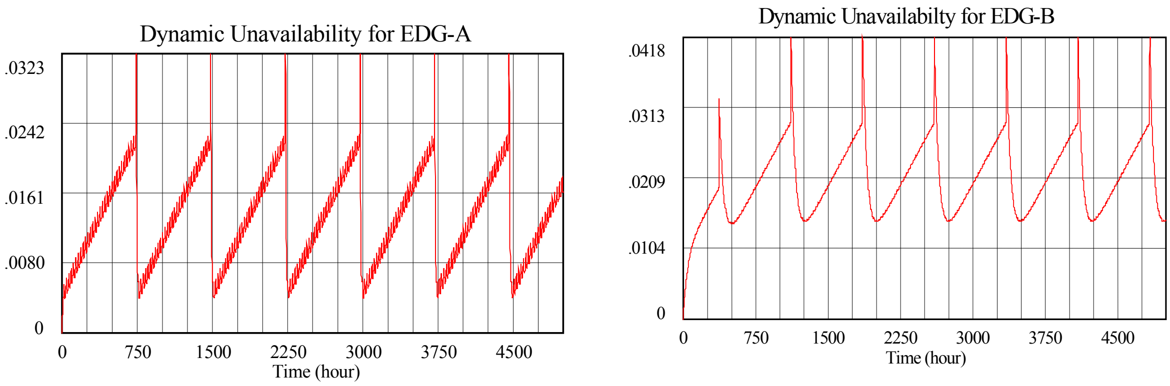
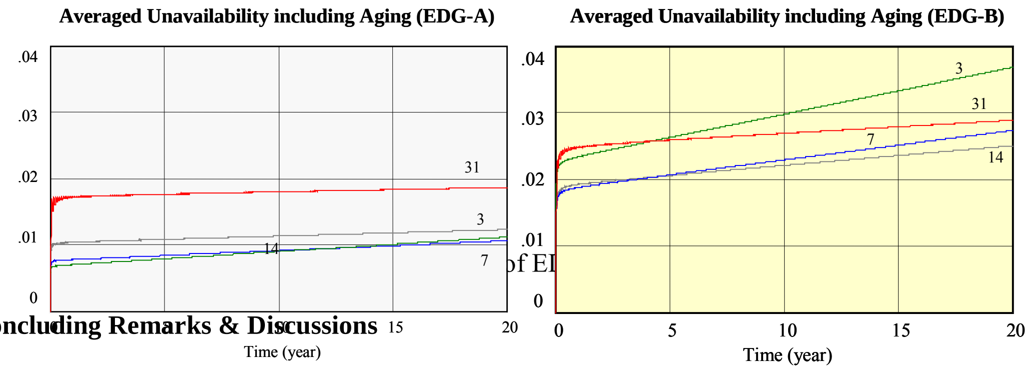


Figure 5. Dynamic Unavailability of EDG-A and EDG-B of YGN 3

The purpose of the dynamic model for EDGs was basically to evaluate the regulation policy for an EDG such as Reg. Guide 1.108 in which test interval for the EDG should be reduced based on the number of failures in the last 100 tests. Therefore we analyzed the reliability of an EDG for the case of each test interval such as 3, 7, 14, and 31 days mentioned in Reg. Guide 1.108 to establish if the reduced test interval can impose an additional risk on EDGs. We also considered an aging effect in the Markov model for an EDG. We used the linear aging model and aging rate from the NUREG/CR-5248. Figure 6 shows the averaged unavailability by considering the aging factor of EDG-A and EDG-B of YGN 3.



5. Concluding Remarks & Discussions

In this research, we introduced the aging researches performed in the IRAC of KAERI. We also presented the development of a component reliability database, KIND, component failure trend Analyses, and the Markov model for an EDG. Recently, we have increased our efforts on an aging PSA, but we are still at an early stage. Even though there is an active research about the component aging related to the seismic PSA and the passive system reliability for the Very High Temperature Reactor (VHTR) in the IRAC, they are at a survey stage. In the NMRC of KAERI, there are advanced studies such as the integrated material database and the structural integrity assessment. Its applications are the determination of a degree of material aging and a life extension of key facility materials.

To make the aging PSA more active in KAERI, we need to share our research experiences and conduct co-operation researches.

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