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An Overview of the Reliability and Availability Data System (RADS)

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Abstract – *The Reliability and Availability Data System (RADS) is a database and analysis code, developed by the Idaho National Engineering and Environmental Laboratory (INEEL) for the U.S. Nuclear Regulatory Commission (USNRC). The code is designed to estimate industry and plant-specific reliability and availability parameters for selected components in risk-important systems and initiating events for use in risk-informed applications. The RADS tool contains data and information based on actual operating experience from U.S. commercial nuclear power plants. The data contained in RADS is kept up-to-date by loading the most current quarter's Equipment Performance and Information Exchange (EPIX) data and by yearly loads of initiating event data from licensee event reports (LERs). The reliability parameters estimated by RADS are (1) probability of failure on demand, (2) failure rate during operation (used to calculate failure to run probability), and (3) time trends in reliability parameters.*

I. INTRODUCTION

In 1994 the Commission directed the staff to prepare a rule to require licensees to report reliability data for selected components to the USNRC. At that time industry started development of a database to replace the Nuclear Plant Reliability Data System (NPRDS). Industry proposed modifying the new database to provide most of the reliability data identified in the draft reliability data rule. The staff recommended that the Commission accept the voluntary approach to providing data. The Commission approved the recommendation.

The Equipment Performance Information Exchange (EPIX) System was developed and is maintained by The Institute for Nuclear Power Operations (INPO) in 1997. INPO developed it to replace NPRDS and to support implementation of the Maintenance Rule and other industry programs. It contains failure and engineering data for key components in each utility's maintenance rule scope. Key components are linked to their subcomponents, supporting components, and piece parts. The mission of EPIX was expanded to provide reliability data (for the voluntary approach). EPIX contains estimates of demands and run times for these components. For a selected set of components it contains observed demands and run times.

Since its inception, EPIX has grown and matured into a useful database. One hundred percent of the utilities submit failure and/or reliability information to EPIX and all are currently submitting information routinely to EPIX.

EPIX data collection system has sophisticated, automated quality assurance tools that provide direct feedback on mistakes to the submitter. INPO calls this set of software tools a "Coach." The EPIX "Coach" has greatly improved the quality of the failure and reliability records. In addition, INPO has undertaken a well organized effort to correct EPIX omissions. These efforts have led to massive improvements in EPIX over the last two plus years.

Because of its structure, EPIX can be monitored effectively from a central location and corrective actions promptly taken to address deficiencies in the data. This structure also allows INPO to track reporting by each unit. This is reported back to the EPIX contact at the unit and also utility senior managers.

These characteristics make EPIX the best available database for use in estimating component failure probabilities and failure rates.

II. FEATURES OF RADS

RADS provides the ability to gather data supplied under this voluntary approach along with other data (Licensee Event Reports [LERs], monthly operating reports, etc.) for analysis in risk-informed applications. The RADS program contains options for the user to:

- Search and select the failure data for a component
- Estimate industry and plant-specific probability of failure on demand and failure rate, and the out-of-service unavailability (to be added)

- Prepare output reports of probability distributions and trends
- Calculate initiating event frequencies

Statistical methods [1] utilized in RADS include:

- Classical statistical methods (maximum likelihood estimates [MLEs] and confidence intervals)
- Bayesian methods
- Tests for homogeneity of the data for deciding whether to pool the data or not
- Empirical Bayes methods
- Methods for trending the reliability parameters over time

The RADS program is loaded with data on those systems and components important to risk for risk-informed applications. Most components loaded into RADS are those that were previously NPRDS "application-coded" components. That is, the components are major components in the most risk-important systems. The total number of component names (BWR and PWR) is less than 150. The major component types are:

- Pumps
- Motor-operated and air-operated valves
- Emergency diesel generators
- Batteries and battery chargers
- Safety and relief valves
- Selected circuit breakers
- Compressors
- Air handling equipment
- Reactor protection system devices

The major systems included in RADS are contained in Table I.

III. Example Component Failure Search and Results

To demonstrate the functionality of RADS, a sample search was created. The search is for motor operated valves (MOVs) in the low pressure injection (LPI or RHR) system. The failure mode searched for is the fail to open (FTO) and the data rage is the range of dates in the entire EPIX database (1997 to 2004). Figure 1 shows one of the available selections. The search is given a name and is saved in the RADS software and can be re-executed as new data becomes available.

Table I. Systems

Boiling Water Reactor Systems
High Pressure Core Spray System
High Pressure Coolant Injection System
Reactor Core Isolation Cooling System
Isolation Condenser System
Low Pressure Coolant Injection System
Main Steam System
Residual Heat Removal System
Service Water System
Component Cooling Water System
Emergency DC Power System
Emergency AC Power System
Reactor Protection System
Heating and Ventilation System
Pressurized Reactor Systems
Auxiliary/Emergency Feedwater System
High Pressure Safety Injection System
Low Pressure Safety Injection System
Residual Heat Removal System
Reactor Coolant System
Main Steam System
Service Water System
Component Cooling Water System
Emergency DC Power System
Emergency AC Power System
Containment Spray System
Ice Condenser System
Containment Fan Cooling System
Containment Isolation System
Reactor Protection System
Heating and Ventilation System

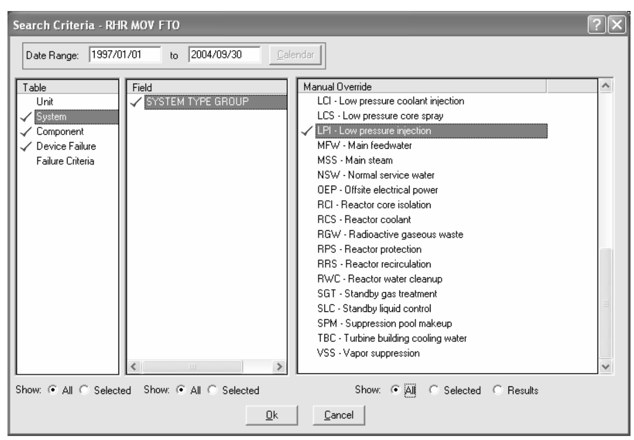

Figure 1. Search criteria for RHR MOVs FTO.

With a search criteria defined and executed, RADS provides analysis tools similar to statistical analysis packages.

Figure 2 shows the results of a poolability analysis of the data. The waterfall chart shows the variation of the selected data between plants. As can be seen, fifty-one plants have a very wide uncertainty distribution, which has zero as the lower bound. These plants did not have any failure records that satisfied the search criteria. The plant names have been blocked out since that information is proprietary. The vertical line in Figure 2 is set at 3.31E-04, this is the maximum likelihood estimate (MLE) for the 'All' case which has a lower limit of 2.26E-04 and an upper limit of 4.69E-04. The confidence band is very small since the number of failures is relatively low and the number of demands is very high.

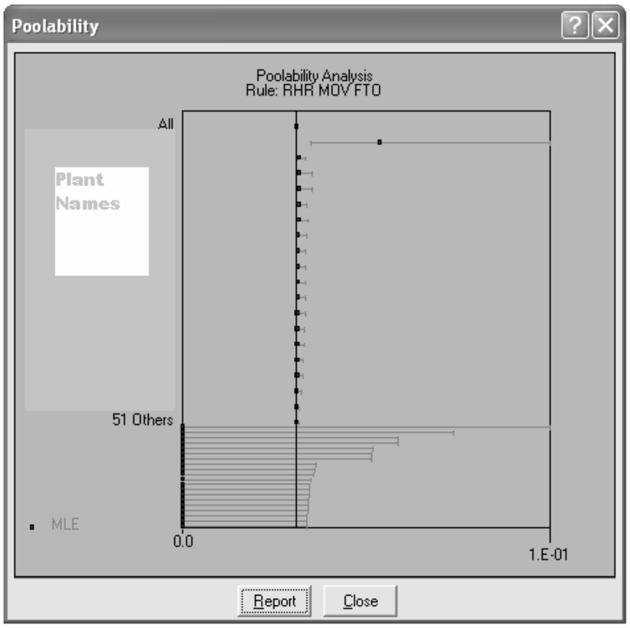

Figure 2. Poolability of selected data.

The line in Figure 2 with the widest confidence limits is based on data from the plant with the fewest reported demands for RHR MOVs to open. The other wide line on the graph, lying entirely to the right of the industry MLE, is from a plant with relatively few demands (the band is wide) and several recorded failures. For a test of poolability, an issue is whether that plant is so different from the rest of the population that it represents a different population and is an outlier. The RADS program answers this question by providing a chi-squared test 'p-value' for the test of whether the data can be pooled. For this data set, the p-value is extremely small and the data show strong reason to reject the hypothesis that the data are homogeneous. Pooling of the data is not recommended.

Figure 3 shows the results of a Bayes analysis of the data. A Jeffreys noninformative prior distribution [1] was selected as an appropriate distribution. This distribution is a beta distribution with mean 0.5 and standard deviation $\sqrt{1/8}$. The data show 23 failures in 69,550 demands. The prior distribution probability of 23 or fewer events in 69,550 demands is only 0.012. This is evidence that the prior distribution is inconsistent with the data. In spite of this inconsistency, a posterior beta distribution maximizing the likelihood of the observed data was found. This is the posterior distribution curve in Figure 3. This distribution puts much more weight on small values of the failure probability.

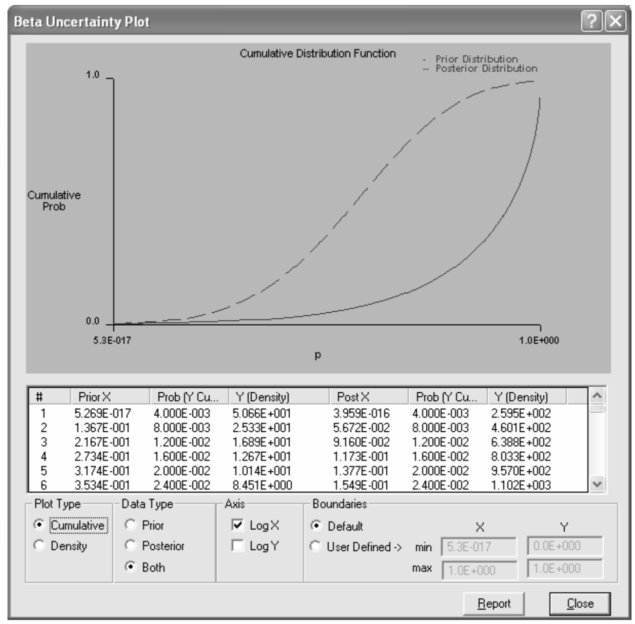

Figure 3. Bayes analysis of selected data.

An Empirical Bayes analysis of the data was performed, see Figure 4. The Empirical Bayes method gives a model of the between-unit variation that was found by the chi-squared test. When the prior distribution is in the beta family of distributions and the failures at each plant are assumed to occur according to a binomial distribution with the plant-specific probability of failure sampled from a beta distribution, then the posterior distribution from a Bayesian update is also in the beta family of distributions. This distribution is used as a prior distribution in a Bayesian update for each plant. Thus, the Empirical Bayes procedure seeks a beta distribution that maximizes the likelihood of the occurrence of the observed data. The Empirical Bayes process yields probability distributions for the failure probability of the component at each plant. These plant-specific distributions can be used in reliability analyses to help quantify the overall uncertainty for system performance.

The vertical line in Figure 4 is set at 3.35E-04, this is the mean for the 'All' case which has a lower limit of 1.39E-04 and an upper limit of 5.99E-04. The 'All' case is a beta distribution with (a = 5.49, b = 16,410). The mean has changed subtly from the MLE from the poolability test. In addition, the uncertainty band has increased. This is an outcome of the Empirical Bayes analysis. The figure also shows the 5th percentile, mean, and 95th percentile of each plants Bayesian update beta distribution.

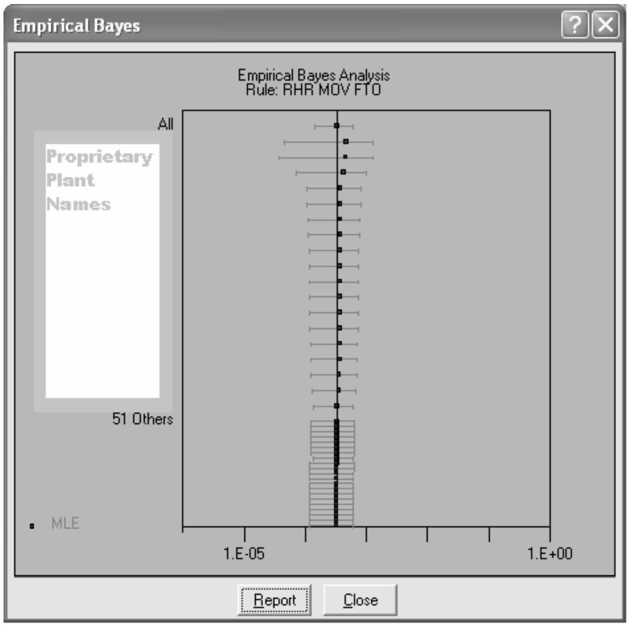

Figure 4. Empirical Bayes analysis of selected data.

Figure 5 shows the fitted trend for the search criteria. RADS uses the 'iteratively re-weighted least squares' method for trend analysis [Ref. 1, p. 7-21]. The p-value for testing the presence of a trend is 0.0293. A small p-value indicates statistically significant evidence for a trend. The customary cutoff for 'statistical significance' is a p-value of 0.05. The residual sum of squares of the weighted transformed counts is 3.135. If the model assumptions are correct, this sum is a chi-squared variate with 6 degrees of freedom. Based on the residual sum of squares, fit appears acceptable.

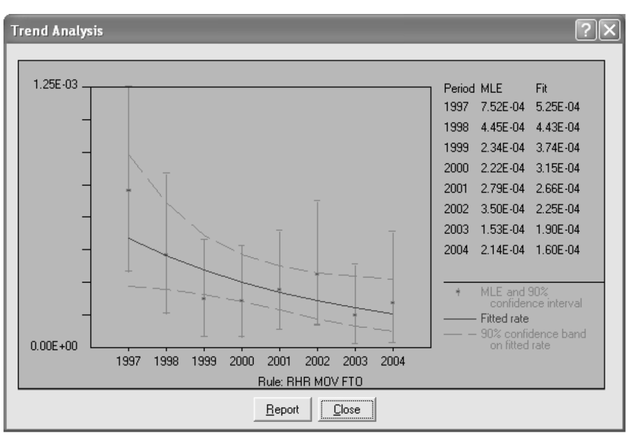

Figure 5. Trend analysis of selected data.

IV. Example Initiating Event Search and Results

To demonstrate the functionality of the initiating event (IE) function of RADS, a sample search was created. The search is for loss of feedwater (LOFW) events at commercial nuclear power plants from 1/1/1987 to 3/31/2004 (the last update of the IE data). The initiating event data is imported into RADS from the Data Trends program funded by the NRC and is derived from licensee event reports (LERs). Figure 6 shows the selection criteria dialog. As with the component analysis, the search criteria are saved for future use.

With a search criteria defined and executed, RADS provides analysis tools similar to statistical analysis packages.

Figure 7 shows the results of a poolability analysis of the data. The waterfall chart shows the variation of the selected data between plants. The plant names have been blocked out since that information is proprietary. The vertical line in Figure 7 is set at 8.04E-02. This is the MLE for the 'All' case, in which all the events are pooled into one event count and all the associated times are summed. This estimate is the MLE if the data are homogeneous and came form a single Poisson distribution. The lower confidence limit is 6.85E-02 and the upper confidence limit is 9.39E-02. The confidence interval is very small since the number of events is relatively low and the amount of time is very high.

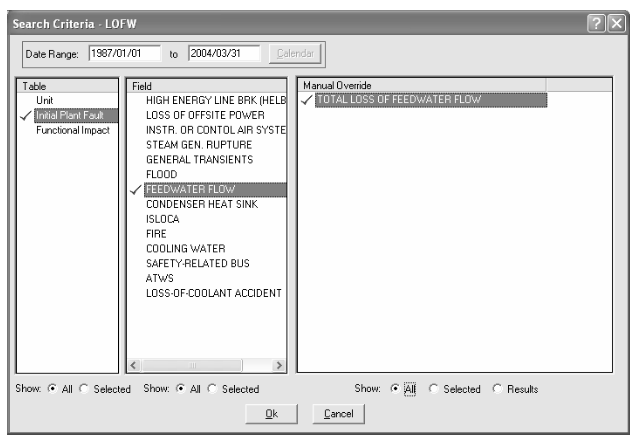

Figure 6. Search criteria for initiating event analysis.

The line in Figure 7 lying entirely to the right of the industry MLE is from a plant with a relatively small amount of reactor critical time (the band is wide) with one or more recorded events. For a test of poolability, an issue is whether that plant is so different from the rest of the population that it represents a different population and is an outlier. The RADS software answers this question by providing a 'p-value' for a chi-squared test of whether the data can be pooled. For this data set, the p-value is extremely small and the data show strong reason to reject the hypothesis of homogeneity. Pooling of the data is not recommended. The single plant with large confidence bounds may have a problem or has suspect data. In these cases, investigation can clear this up and that plant may be removed from the analysis and the tests performed again.

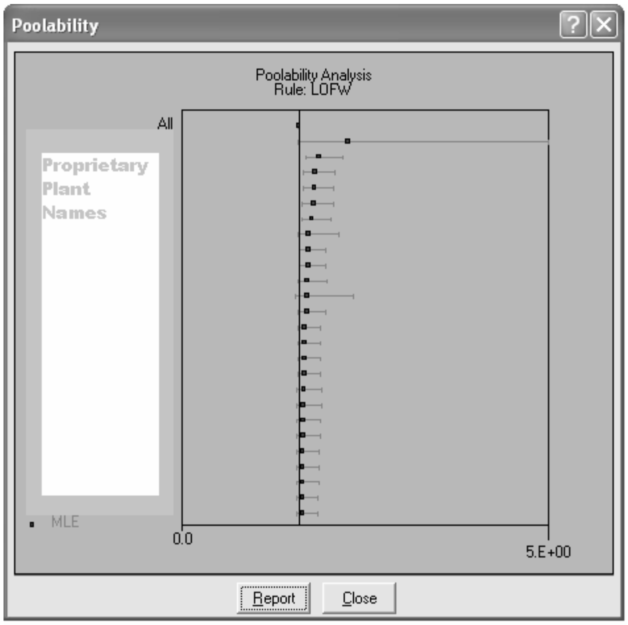

Figure 7. Poolability analysis of selected initiating event data.

Figure 8 shows the results of a Bayes analysis of the data. A Gamma prior distribution with a wide uncertainty was selected as an appropriate distribution. The poolability of units was rejected, with a very low p-value.

An Empirical Bayes analysis of the initiating event data was performed, see Figure 9. Except for being a gamma distribution, this is similar to the component Empirical Bayes analysis described earlier in this report. The vertical line in Figure 9 is set at 8.09E-02, this is the mean for the 'All' case which has a lower limit of 7.04E-03 and an upper limit of 2.23E-01. The 'All' case is a gamma distribution with (a = 1.27, b = 15.69). The mean has changed subtly from the MLE from the poolability test. In addition, the uncertainty band has increased. This is an outcome of the Empirical Bayes analysis. The figure also shows the 5th percentile, mean, and 95th percentile of each plants Bayesian update beta distribution.

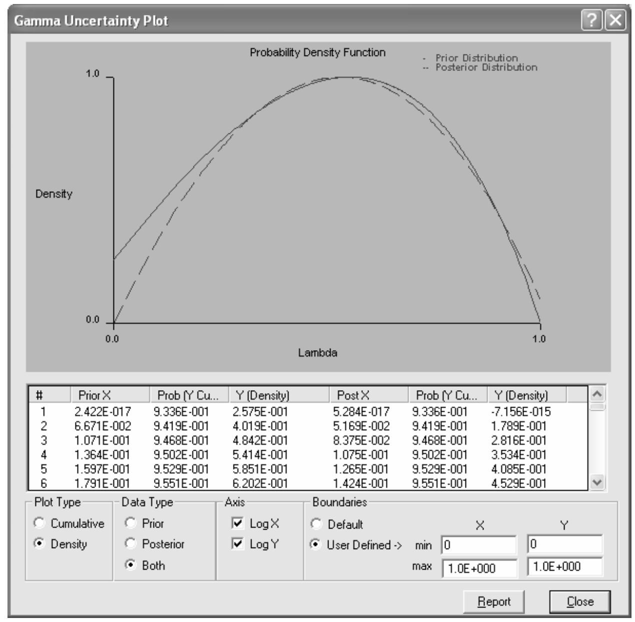

Figure 8. Bayes analysis of selected initiating event data.

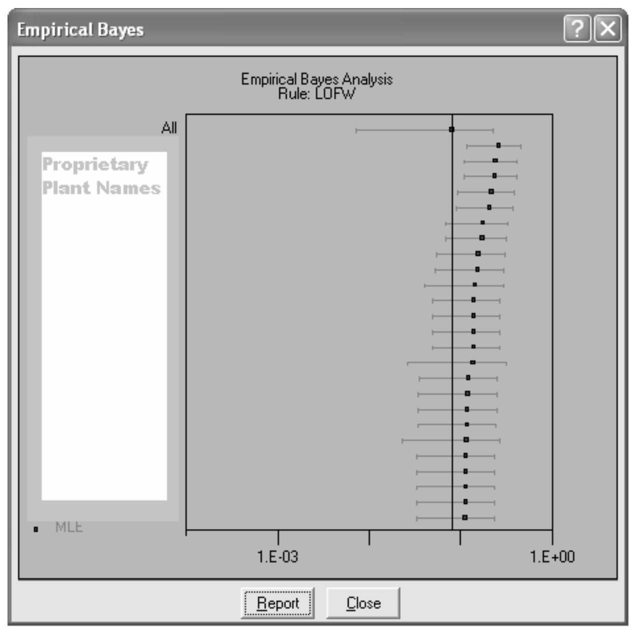

Figure 9. Empirical Bayes analysis of selected initiating event data.

Figure 10 shows the fitted trend for the search criteria using a Bayes estimate with a constrained non-informative prior. The p-value for testing the presence of a trend is 0.0002 (the trend is decreasing). A small value indicates strong evidence for a trend. The residual sum of squares of the weighted transformed counts is 23.7. If the model assumptions are correct, this sum is a chi-squared variate with 15 degrees of freedom. Based on residual sum of squares, the fit appears acceptable.

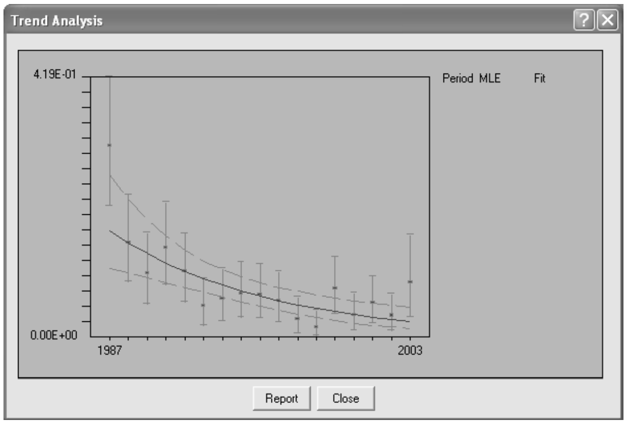

Figure 10. Trend analysis of selected initiating event data.

III. CONCLUSIONS

The RADS software has been used to show the probability on demand of RHR MOVs and the critical yearly frequency of the LOFW initiating event. Both were shown to exhibit some variation between plants with a possible recommendation of using plant-specific versus industry wide values for specific risk or reliability analyses and possible research into specific plants to identify weaknesses. Both analyses showed statistically significant decreasing trends over the time-frame of the criteria. RADS can keep the definitions of the analyses and the selection made as new, more current, data is added to the base dataset.

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