INEL-95/00381
CONF-950914--7

PARAMETER UNCERTAINTY FOR ASP MODELS

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ABSTRACT

The steps involved to incorporate parameter uncertainty into the Nuclear Regulatory Commission (NRC) accident sequence precursor (ASP) models is covered in this paper. Three different uncertainty distributions (i.e., lognormal, beta, gamma) were evaluated to determine the most appropriate distribution. From the evaluation, it was determined that the lognormal distribution will be used for the ASP models uncertainty parameters. Selection of the uncertainty parameters for the basic events is also discussed. This paper covers the process of determining uncertainty parameters for the supercomponent basic events (i.e., basic events that are comprised of more than one component which can have more than one failure mode) that are utilized in the ASP models. Once this is completed, the ASP model is ready to be utilized to propagate parameter uncertainty for event assessments.

I. INTRODUCTION

This paper discusses the steps involved to incorporate parameter uncertainty into the Nuclear Regulatory Commission (NRC) accident sequence precursor (ASP) models. The steps include the evaluation of different uncertainty distributions to determine the best representative distribution, selection of uncertainty distribution parameters, and analysis of the ASP models once parameter uncertainty is incorporated.

The ASP models were developed using the System Analysis Programs for Hands-on Integrated Reliability Evaluation (SAPHIRE)[1] computer code. The SAPHIRE computer code consists of four computer programs: the Integrated Reliability and Risk Analysis System (IRRAS), the System Analysis and Risk Assessment (SARA), the Models and Results Database (MAR-D), and the Fault Tree/Event Tree/Piping and Instrumentation Diagram (FEP). The developed ASP models contain train-level front line safety systems. The train-level models contain two types of basic events. The first type of basic event consists of a single component with a single failure mode which are utilized in most probabilistic risk assessments (PRAs). The second type of basic event is a supercomponent basic event which consists of one or more components which can have one or more failure modes. This combination of train-level models with supercomponents greatly simplifies the logic modeling and the resulting number of minimal accident sequence cutsets.

II. REPRESENTATIVE DISTRIBUTIONS

To determine which uncertainty distribution should be used for the ASP model basic events, three different uncertainty distributions were examined. The distributions examined were lognormal,

beta, and gamma. The three distributions were compared to determine which would be the most appropriate. They were compared by evaluating three different supercomponent basic events. The three supercomponent basic events used for the comparison consisted of two "simple" and one "complex" supercomponent. A "simple" supercomponent basic event is a supercomponent basic event with three or less individual components and/or failure modes. A "complex" supercomponent basic event is a supercomponent basic event with four or more individual components and/or failure modes.

The three supercomponent basic events were converted into IRRAS fault trees. Figure 1 gives an illustration of how to convert a "complex" supercomponent into an IRRAS fault tree. The individual components for the "complex" and one "simple" supercomponent were fed into an "OR" gate. The other "simple" supercomponent had its individual components feed into an "AND" gate. The means and error factors for each of the individual components were put into the IRRAS database; also, correlation of identical individual components was completed prior to analyzing the supercomponent fault trees. The fault trees were then analyzed using Latin Hypercube with 3,000 samples.

The results from the analysis were used to determine an error factor for a lognormal distribution, the b parameter for a beta distribution, and the r parameter for a gamma distribution. These parameters along with the original mean obtained from the analysis, were put into individual basic events. These basic events were then evaluated using Latin Hypercube with 3,000 samples to see which distribution (lognormal, beta, or gamma) best fits the original supercomponent cumulative percentile values.

A Kolmogorov-Smirnov (K-S) test was performed on the three different supercomponents to see which distributions should be rejected from further consideration when performing parameter uncertainty analyses. In performing the test, a five percent significance level was chosen as the hypothesis rejection criteria for the different distributions (i.e., lognormal, beta, gamma). From the five percent significance level and the nineteen data points (i.e., $D_n(\alpha) = D_{19}(0.05)$), a rejection criteria of 0.301 was determined. The determined rejection criteria was compared to the maximum difference between the original distribution percentiles and the three different distributions percentiles. The K-S test showed that the beta and gamma distributions should be rejected for the "complex" supercomponent and "simple" supercomponent that had its individual components "ANDed" together. The K-S test showed that all three distributions percentiles were fairly close to the original percentiles for the other "simple" supercomponent which had its individual components "ORed" together. From these results, it was recommended that the lognormal distribution should be used when modeling the supercomponent basic events. Table 1 gives the results of the K-S test performed on the supercomponents. Figure 2 shows the cumulative distribution function for the three "complex" supercomponent distributions percentiles and the original percentiles. Evaluating the figure confirms the K-S test results that the lognormal distribution best matches the original distribution percentiles.

III. SELECTION OF UNCERTAINTY PARAMETERS

The next step in this uncertainty analysis process is to determine the distribution parameters for the ASP model basic events. If the basic event is a single component, this step is straight forward. The uncertainty parameter to be used by the single component basic event is the value that was presented with the mean (or median) value from wherever the component data was found. (Note: Care should be taken not to mix mean values and standard deviations (or error factors) for a particular basic event from different databases.) The only exception to this criteria is for basic events with distribution probabilities that exceed a value of 1.0 greater than 1 percent of the time (since probabilities cannot exceed 1.0). For these basic events and the human actions used in the ASP models, the distribution should most likely be a beta distribution. The b parameters for the beta distributions that will be used are calculated using a constrained noninformative prior.[2] This b parameter used in the beta distribution maximizes the uncertainty associated with the basic event around a known mean value with a lower bound constraint of zero and an upper bound constraint of one. This same thinking is used for the initiating events distribution parameter, except the initiating events will be modeled with a constrained noninformative prior for poisson events. Consequently, the initiating events are modeled as a gamma distribution with the mean value specified by the analyst and the shape parameter as 0.5.

The distribution parameters for supercomponent basic events are more complicated due to the fact that the supercomponents consist of multiple components or failure modes combined together. These multiple components or failure modes are combined into a supercomponent by adding or multiplying individual component failure probabilities. The uncertainty in this combination step must be preserved to have consistent and defensible results from the uncertainty analysis. Three methods could be used to evaluate the supercomponent to preserve its uncertainty value. The three methods are (1) evaluate the supercomponent failure probability using Taylor series expansion, (2) evaluate the supercomponent failure probability using a Monte Carlo or (Latin Hypercube) sampling program such as @RISK, or (3) evaluate the supercomponent failure probability using the Monte Carlo analysis that is internal to IRRAS. Methods 1 and 2 require the supercomponent logic to be converted into an equation that can be evaluated. Method 3 requires the supercomponent logic to be converted into an IRRAS fault tree to be evaluated. The time to create the logic equation or IRRAS fault tree and generate results from the three different methods turned out to be similar. But for adding parameter uncertainty to the ASP models, Method 3 is recommended. The justification for using Method 3 is that the logic for each supercomponent is created and saved in the model database where it can be used to determine the supercomponent uncertainty parameters or as full logic when evaluating the ASP model. If, at a later date, additional complexity is desirable in the fault tree models, the supercomponent fault trees will already be completed.

The supercomponent means and error factors can now be determined by evaluating the constructed IRRAS fault trees. These IRRAS fault trees should be evaluated using Latin Hypercube sampling (LHS) with approximately 3,000 samples. The reason for using LHS with 3,000 samples stems from results of analyses performed using Monte Carlo and Latin Hypercube sampling at sample sizes ranging from 100 to 9,000. The analysis showed that the mean and percentiles converged with sample sizes greater than 3,000 for Latin Hypercube and 5,000 for Monte Carlo sampling. The output uncertainty parameters from IRRAS are used to calculate the supercomponents error factors. There are different ways that an error factor can be derived from the uncertainty parameters that IRRAS calculates. However, after evaluating error factors by using the various equations (e.g., 95th/50th, 50th/5th, SQRT(95th/5th)) the recommended equation is the ratio of the 95th to the 50th percentile. This equation generally gave slightly conservative results compared to the other equations.

Additionally, data correlation of basic events needs to be addressed. Basic events that have data dependencies should be correlated together. Data dependencies include data used to generate the failure probability for more than one basic event of the same type and same failure mode. IRRAS handles these data dependencies by completely correlating the Monte Carlo sampling for events that are correlated. No partial correlations are currently allowed in IRRAS. Consequently, for those components that have identical failure probabilities, failure modes, and uncertainties, the basic events modeled in the fault trees were identified as being correlated. The supercomponent basic events should also be correlated if they contain the same individual components with the same failure modes and failure probabilities. A consistent naming scheme for the correlation classes was also developed.

IV. ASP UNCERTAINTY ANALYSIS

The last step in the uncertainty analysis process is to incorporate the parameter uncertainty into the ASP models. The ASP models can be analyzed for uncertainty once the uncertainty parameters for single component and supercomponent basic events are loaded into the ASP model database. Once this step is performed, the ASP model is ready to allow the analyst to propagate parameter uncertainty for event assessments. When performing the uncertainty propagation, Latin Hypercube sampling with approximately 3,000 samples should be used to ensure convergence of the results.

In conclusion, this paper demonstrated the processes performed in determining which uncertainty distribution was the most appropriate to be used in the ASP models. The paper also demonstrated the steps needed to incorporate parameter uncertainty in the IRRAS ASP data bases (currently one database exists for each commercial nuclear power plant site). These steps could be used to incorporate parameter uncertainty into any PRA data base irregardless of the logic model complexities. While some of the steps involved are specific to the IRRAS PRA code (e.g., the constrained noninformative prior distribution), most of the uncertainty development is applicable to many other software codes.

ACKNOWLEDGMENTS

This work was partially supported by the U.S. Nuclear Regulatory Commission, under DOE Idaho Field Office, Contract DE-AC07-94ID13223.

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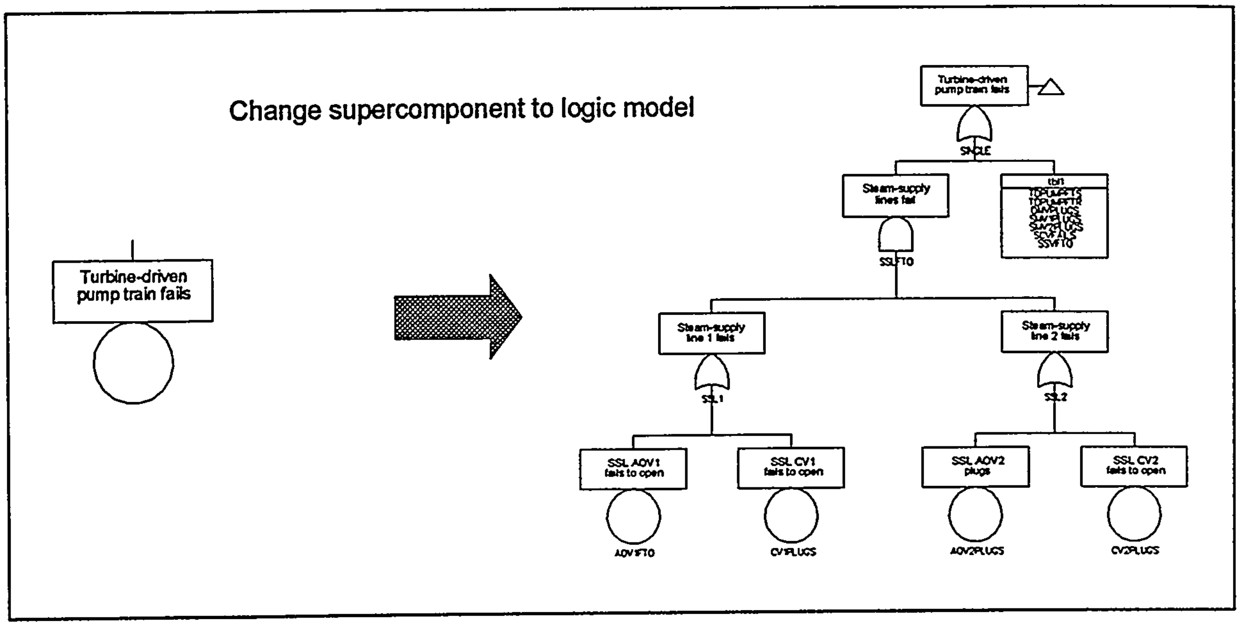

Figure 1. Diagram representing the change of a supercomponent into a detailed logic model.

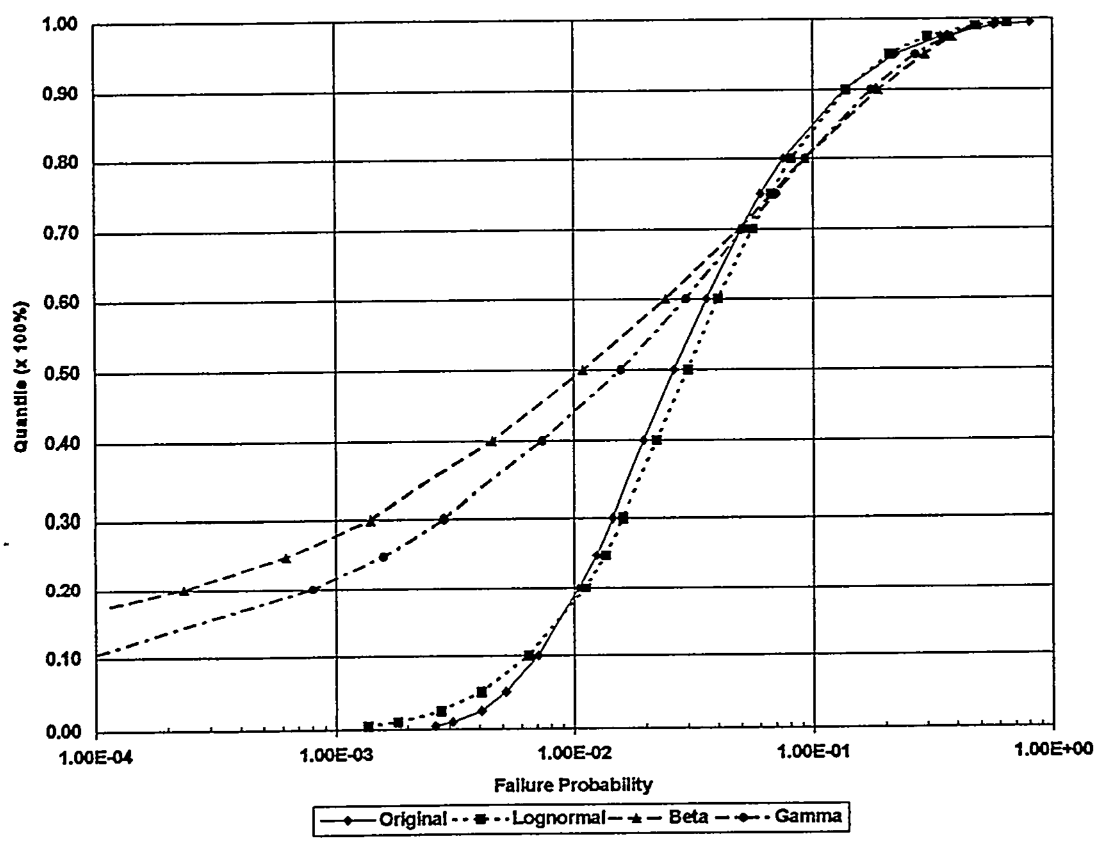

Figure 2. "Complex" supercomponent uncertainty distribution comparison.

Table 1. K-S test performed on the uncertainty distributions.

Type of supercomponent	Distribution types	ω	$\omega > D_{19}$ (0.05)	Accept or Reject
"simple" supercomponent "ORed" together	lognormal	0.01	no	Accept
	beta	0.07	no	Accept
	gamma	0.06	no	Accept
"simple" supercomponent "ANDed" together	lognormal	0.02	no	Accept
	beta	0.35	yes	Reject
	gamma	0.35	yes	Reject
"complex" supercomponent "ORed" together	lognormal	0.05	no	Accept
	beta	0.37	yes	Reject
	gamma	0.31	yes	Reject