Estimation of Uncertainty Distributions for Internal Flood Initiators Using Parametric Sensitivity Study

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Abstract: Appendix A of EPRI Technical Report 1013141 lists the failure rate uncertainty distributions of the various flooding modes obtained from industry data for the various piping systems that were used in calculating initiating event frequencies for various PRA internal flood scenarios. To help understand the effect on the uncertainty associated with the initiating frequency for an internal flood scenario based on contributions from various water systems, a parametric study was performed in which each of the system piping failure rates was fitted to a cumulative distribution based on the reported 5th, 50th, and 95th percentiles. An additional source of uncertainty was the estimate of pipe diameters and lengths for those recorded water sources obtained during plant walkdowns. A distribution of values was then assigned to these parameters to help bound the estimated uncertainty associated with obtaining this type of data in the field. A parametric analysis was then able to be performed using @RISK, which is an iterative risk analysis tool used with Microsoft Excel. The modeled uncertainty distributions were used as the input for the @RISK sampling algorithm to determine the resultant distribution results for each modeled internal flood initiator, accounting for uncertainty associated with both industry data and estimates of the piping geometry and configuration obtained from the field.

Keywords: PRA, Internal Flood, Uncertainty Distribution

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1. INTRODUCTION

The purpose of this parametric uncertainty analysis was to develop uncertainty distributions for internal flood initiators utilized within a PRA model to help support the global parametric analysis of a PRA model's top event, such as core damage. Pipe failure and rupture frequencies reported by the Electric Power Research Institute (EPRI) [1] were identified and applied to piping data collected in the field, such as pipe diameters and lengths. The pipe lengths were multiplied by the corresponding flooding mode frequencies (1/yr-ft) to result in a yearly initiating event for internal flooding due to that particular piping system. The results were summed for the various piping systems within a given flood area to arrive at an overall internal flood initiating frequency for a given flood mode (i.e., spray, general flood, or major flood) for that particular area. Then, using the uncertainty distribution parameters given in Appendix A of the EPRI Technical Report [1], the mean failure estimates were replaced with a cumulative distribution constructed from the reported percentiles using @RISK modeling software in Excel [2]. Pipe diameter and length estimates were also modeled with assigned uncertainty distributions based on engineering judgment and used as an input in deriving an overall uncertainty distribution for each of the developed internal flood initiators.

2. DISCUSSION OF METHODOLOGY

The discussion of how pipe rupture frequencies were calculated and the methodology chosen for the parametric analysis is provided in the following sections.

2.1. Development of Rupture Frequencies

The total rupture frequency, ρ, is the summation of different pipe segments, i, each of length, L, failure probability (1/yr-ft), λ, and conditional probability of rupture given failure, $P(R|F)$, and is represented below by Eq. (1):

$$\rho = \sum_i \rho_i = \sum_i L_i \cdot \lambda_i \cdot P_i \langle R | F \rangle \qquad (1)$$

Table 1 below lists representative rupture frequencies for the various flooding modes (e.g., spray, general flooding, and major flooding) from Appendix A of the EPRI report [1] for typical water systems at a Pressurized Water Reactor (PWR) plant. The frequencies are tabulated based on a per-year and per-length of piping for a particular range of pipe diameters. These values represent the product of λ and P(R|F) shown above in Eq. (1).

Table 1: Water System Flooding Mode Frequencies

Water System and Tables from EPRI Report [1]	Diameter (in)	Flooding Mode	Mean Rupture Rate (/ft-yr)
Service Water (Sea Water) Tables A-22 through A-24	0 to 2	Spray	7.38E-06
	2 to 4	Spray	7.78E-06
	4 to 10	Spray	2.33E-06
	10+	Spray	4.89E-07
	0 to 2	Flood	1.17E-06
	2 to 4	Flood	1.24E-06
	4 to 10	Flood	3.70E-07
	10+	Flood	7.79E-08
	0 to 2	Major Flood	N/A
	2 to 4	Major Flood	1.45E-07
	4 to 10	Major Flood	4.32E-08
	10+	Major Flood	9.06E-09
Fire Protection Tables A-26 through A-28	0 to 4	Spray	1.34E-07
	4 to 6	Spray	2.09E-07
	6+	Spray	1.02E-06
	0 to 4	Flood	4.09E-08
	4 to 6	Flood	6.48E-08
	6+	Flood	3.14E-07
	0 to 4	Major Flood	4.41E-08
	4 to 6	Major Flood	6.97E-08
	6+	Major Flood	3.36E-07
Closed Cooling Table A-30	0+	Spray	2.28E-08
	0+	Flood	6.46E-09
	0 to 3	Major Flood	N/A
	3+	Major Flood	9.15E-10
Emergency Core Cooling Tables A-32 through A-34	0 to 2	Spray	N/A
	2 to 6	Spray	5.30E-08
	6 to 10	Spray	1.60E-08
	10+	Spray	2.41E-07
	0 to 2	Flood	N/A
	2 to 6	Flood	1.42E-08
	6 to 10	Flood	4.17E-09
	10+	Flood	7.35E-08
	0 to 2	Major Flood	N/A
	2 to 6	Major Flood	1.71E-09
	6 to 10	Major Flood	4.97E-10
	10+	Major Flood	9.14E-09

Table 1: Water System Flooding Mode Frequencies (cont'd.)

Water System and Tables from EPRI Report [1]	Diameter (in)	Flooding Mode	Mean Rupture Rate (/ft-yr)
Condensate Tables A-45 through A-47	0 to 2	Spray	N/A
	2+	Spray	1.86E-07
	0 to 2	Flood	N/A
	2+	Flood	1.21E-07
	0 to 2	Major Flood	N/A
	2+	Major Flood	6.38E-08
Feedwater Tables A-45 through A-47	0 to 2	Spray	N/A
	2+	Spray	5.37E-06
	0 to 2	Flood	N/A
	2+	Flood	3.49E-06
	0 to 2	Major Flood	N/A
	2+	Major Flood	1.84E-06
Circulating Water Table A-29	All	Spray	3.22E-07
	All	Flood	2.01E-07
	All	Major Flood	1.14E-07

2.2. Development of Event Frequencies

Flooding event frequencies were calculated by multiplying system pipe lengths, which were obtained from plant walkdowns, by the corresponding frequency for a particular pipe diameter found in Table 1. Table 2a lists a typical data sheet that combines walkdown data with failure rates to arrive at spray, general flooding, and major flooding event frequencies for the hypothetical flood scenario group identified as FLOOD-01. Each of the values listed under the column heading "Rupture Frequency" represent the product $L_i \cdot \lambda_i \cdot P_i(R|F)$ identified above in Eq. (1). The summation of these individual frequencies for each identified water source constituted the initiating event frequency for each of the spray, general flooding, and major flooding events associated with scenario group FLOOD-01.

Table 2a: Flooding Event Frequencies for FLOOD-01 Scenarios

Spray Scenario FLOOD-01-SPR

Flood Source	**Pipe Diameter (in)**	**Pipe Length (ft)**	**EPRI Category**	**Mean Failure Rate (/yr-ft)**	**Rupture Frequency (/yr)**	**Spray Vulnerability**
Chilled Water	12	50	Closed Cooling	2.05E-07	1.20E-05	Y
SW	2	50	Service Water	8.25E-06	4.82E-04	Y
RHR	12	50	ECCS	2.79E-07	1.63E-05	Y
					Frequency:	**5.10E-04**

General Flooding Scenario FLOOD-01-FLD

Flood Source	**Pipe Diameter (in)**	**Pipe Length (ft)**	**EPRI Category**	**Mean Failure Rate (/yr-ft)**	**Rupture Frequency (/yr)**	**Flooding Vulnerability**
Chilled Water	12	50	Closed Cooling	7.53E-09	4.39E-07	Y
SW	2	50	Service Water	1.31E-06	7.67E-05	Y
RHR	12	50	ECCS	8.60E-08	5.02E-06	Y
					Frequency:	**8.21E-05**

Table 2a: Flooding Event Frequencies for FLOOD-01 Scenarios (cont'd.)

Major Flooding Scenario FLOOD-01-MAJ						
Flood Source	**Pipe Diameter (in)**	**Pipe Length (ft)**	**EPRI Category**	**Mean Failure Rate (/yr-ft)**	**Rupture Frequency (/yr)**	**Flooding Vulnerability**
Chilled Water	12	50	Closed Cooling	1.08E-09	6.28E-08	Y
SW	2	50	Service Water	1.67E-07	9.77E-06	Y
RHR	12	50	ECCS	1.07E-08	6.24E-07	Y
					Frequency:	**1.05E-05**

To illustrate use of the methodology for other hypothetical internal flood scenarios, two other tables are presented below, which represent scenario groups FLOOD-02 and FLOOD-03 in Tables 2b And 2c, respectively. It should be noted that for some identified water sources, their location behind an obstruction, such as a non-watertight door, could preclude them from being a spray hazard, but in other situations may allow them to be a flood hazard for larger flow rates. This is identified under the column identified as "Spray Vulnerability," with an applicable spray source denoted as "Y" and those incapable of causing spray damage identified as "N." For consistency, the other tables for general and major flooding also contain a similar column, denoted as "Flooding Vulnerability," for applicability to equipment damage due to water submergence.

Table 2b: Flooding Event Frequencies for FLOOD-02 Scenarios

Spray Scenario FLOOD-02-SPR						
Flood Source	**Pipe Diameter (in)**	**Pipe Length (ft)**	**EPRI Category**	**Mean Failure Rate (/yr-ft)**	**Rupture Frequency (/yr)**	**Spray Vulnerability**
Chilled Water	4	50	Closed Cooling	2.05E-07	1.20E-05	Y
FPC & Cleanup	2	100	Closed Cooling	2.05E-07	2.39E-05	Y
CC	4	50	Closed Cooling	2.05E-07	1.20E-05	Y
CC	2	50	Closed Cooling	2.05E-07	1.20E-05	Y
Chilled Water	4	40	Closed Cooling	2.05E-07	9.56E-06	Y
Chilled Water	4	50	Closed Cooling	2.05E-07	1.20E-05	Y
CC	4	50	Closed Cooling	2.05E-07	1.20E-05	Y
CC	2	50	Closed Cooling	2.05E-07	1.20E-05	Y
					Frequency:	**1.05E-04**
General Flooding Scenario FLOOD-02-FLD						
Flood Source	**Pipe Diameter (in)**	**Pipe Length (ft)**	**EPRI Category**	**Mean Failure Rate (/yr-ft)**	**Rupture Frequency (/yr)**	**Flooding Vulnerability**
Chilled Water	4	50	Closed Cooling	7.53E-09	4.39E-07	Y
FPC & Cleanup	2	100	Closed Cooling	7.53E-09	8.79E-07	Y
CC	4	50	Closed Cooling	7.53E-09	4.39E-07	Y
CC	2	50	Closed Cooling	7.53E-09	4.39E-07	Y
Chilled Water	4	40	Closed Cooling	7.53E-09	3.52E-07	Y
Chilled Water	4	50	Closed Cooling	7.53E-09	4.39E-07	Y
CC	4	50	Closed Cooling	7.53E-09	4.39E-07	Y
CC	2	50	Closed Cooling	7.53E-09	4.39E-07	Y
					Frequency:	**3.87E-06**

Table 2b: Flooding Event Frequencies for FLOOD-02 Scenarios (cont'd.)

Major Flooding Scenario FLOOD-02-MAJ						
Flood Source	**Pipe Diameter (in)**	**Pipe Length (ft)**	**EPRI Category**	**Mean Failure Rate (/yr-ft)**	**Rupture Frequency (/yr)**	**Flooding Vulnerability**
Chilled Water	4	50	Closed Cooling	1.08E-09	6.28E-08	Y
FPC & Cleanup	2	100	Closed Cooling	1.08E-09	1.26E-07	Y
CC	4	50	Closed Cooling	1.08E-09	6.28E-08	Y
CC	2	50	Closed Cooling	1.08E-09	6.28E-08	Y
Chilled Water	4	40	Closed Cooling	1.08E-09	5.02E-08	Y
Chilled Water	4	50	Closed Cooling	1.08E-09	6.28E-08	Y
CC	4	50	Closed Cooling	1.08E-09	6.28E-08	Y
CC	2	50	Closed Cooling	1.08E-09	6.28E-08	Y
					Frequency:	**5.52E-07**

Table 2c: Flooding Event Frequencies for FLOOD-03 Scenarios

Spray Scenario FLOOD-03-SPR						
Flood Source	**Pipe Diameter (in)**	**Pipe Length (ft)**	**EPRI Category**	**Mean Failure Rate (/yr-ft)**	**Rupture Frequency (/yr)**	**Spray Vulnerability**
Fire Water	3	80	Fire Protection	1.46E-07	1.36E-05	Y
Chilled Water	6	30	Closed Cooling	2.05E-07	7.17E-06	Y
Fire Water	3	20	Fire Protection	1.46E-07	3.40E-06	Y
Chilled Water	6	30	Closed Cooling	2.05E-07	7.17E-06	Y
Chilled Water	3	20	Closed Cooling	2.05E-07	4.78E-06	N
Fire Water	3	100	Fire Protection	1.46E-07	1.70E-05	N
Chilled Water	2	20	Closed Cooling	2.05E-07	4.78E-06	N
Fire Water	3	50	Fire Protection	1.46E-07	8.51E-06	N
Chilled Water	3	30	Closed Cooling	2.05E-07	7.17E-06	N
Chilled Water	2	30	Closed Cooling	2.05E-07	7.17E-06	N
Fire Water	1	100	Fire Protection	1.46E-07	1.70E-05	N
Fire Water	1	3	Fire Protection	1.46E-07	5.11E-07	N
Chilled Water	4	20	Closed Cooling	2.05E-07	4.78E-06	Y
Chilled Water	4	20	Closed Cooling	2.05E-07	4.78E-06	Y
					Frequency:	**4.09E-05**

Table 2c: Flooding Event Frequencies for FLOOD-03 Scenarios (cont'd.)

General Flooding Scenario FLOOD-03-FLD

Flood Source	Pipe Diameter (in)	Pipe Length (ft)	EPRI Category	Mean Failure Rate (/yr-ft)	Rupture Frequency (/yr)	Flooding Vulnerability
Fire Water	3	80	Fire Protection	4.83E-08	4.50E-06	Y
Chilled Water	6	30	Closed Cooling	7.53E-09	2.64E-07	Y
Fire Water	3	20	Fire Protection	4.83E-08	1.13E-06	Y
Chilled Water	6	30	Closed Cooling	7.53E-09	2.64E-07	Y
Chilled Water	3	20	Closed Cooling	7.53E-09	1.76E-07	Y
Fire Water	3	100	Fire Protection	4.83E-08	5.63E-06	Y
Chilled Water	2	20	Closed Cooling	7.53E-09	1.76E-07	Y
Fire Water	3	50	Fire Protection	4.83E-08	2.82E-06	Y
Chilled Water	3	30	Closed Cooling	7.53E-09	2.64E-07	Y
Chilled Water	2	30	Closed Cooling	7.53E-09	2.64E-07	Y
Fire Water	1	100	Fire Protection	4.83E-08	5.63E-06	Y
Fire Water	1	3	Fire Protection	4.83E-08	1.69E-07	Y
Chilled Water	4	20	Closed Cooling	7.53E-09	1.76E-07	Y
Chilled Water	4	20	Closed Cooling	7.53E-09	1.76E-07	Y
					Frequency:	**2.16E-05**

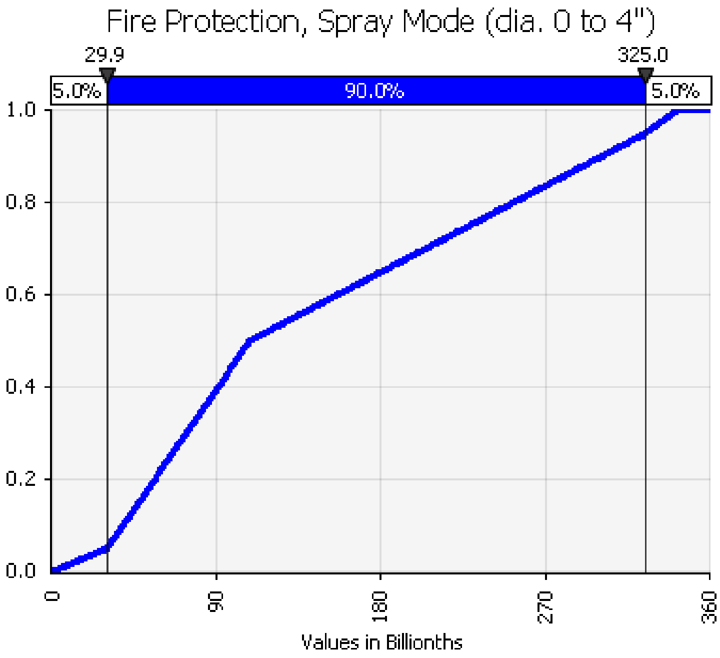
Major Flooding Scenario FLOOD-03-MAJ

Flood Source	Pipe Diameter (in)	Pipe Length (ft)	EPRI Category	Mean Failure Rate (/yr-ft)	Rupture Frequency (/yr)	Flooding Vulnerability
Fire Water	3	80	Fire Protection	4.84E-08	4.52E-06	Y
Chilled Water	6	30	Closed Cooling	1.08E-09	3.77E-08	Y
Fire Water	3	20	Fire Protection	4.84E-08	1.13E-06	Y
Chilled Water	6	30	Closed Cooling	1.08E-09	3.77E-08	Y
Chilled Water	3	20	Closed Cooling	1.08E-09	2.51E-08	Y
Fire Water	3	100	Fire Protection	4.84E-08	5.65E-06	Y
Chilled Water	2	20	Closed Cooling	1.08E-09	2.51E-08	Y
Fire Water	3	50	Fire Protection	4.84E-08	2.82E-06	Y
Chilled Water	3	30	Closed Cooling	1.08E-09	3.77E-08	Y
Chilled Water	2	30	Closed Cooling	1.08E-09	3.77E-08	Y
Fire Water	1	100	Fire Protection	4.84E-08	5.65E-06	Y
Fire Water	1	3	Fire Protection	4.84E-08	1.69E-07	Y
Chilled Water	4	20	Closed Cooling	1.08E-09	2.51E-08	Y
Chilled Water	4	20	Closed Cooling	1.08E-09	2.51E-08	Y
					Frequency:	**2.02E-05**

2.3. Development of Probability Distributions

Appendix A of EPRI Technical Report 1013141 [1] lists the percentiles of the rupture rates for the various flooding modes for each of the various piping systems that were considered in the analysis. To help understand the impact on uncertainty from the various pipe failure rate distributions, a parametric study was performed in which each of the mean rupture frequencies were fitted to a cumulative distribution using the reported 5th, 50th, and 95th percentiles. That is, the previous mean failure estimates for each of the flooding failure modes, i.e., spray, flood, and major flood, in Table 1 above were replaced with a distribution defined by an @RISK function. The process involved replacement of the mean values in those cells of an Excel spreadsheet with the @RISK spreadsheet function RiskCumul(min,max,{X1,X2,X3},{p1,p2,p3}). The placeholder "min" represents the minimum value for the distribution, which was arbitrarily chosen as zero, and the maximum value ("max") was the result of the 95th percentile divided by 0.95. The array values {X1,X2,X3} represent the actual rupture rates at the 5th, 50th, and 95th percentile, respectively. Likewise, the array {p1,p2,p3} are the respective fractional values, i.e., 0.05, 0.50, and 0.95. To illustrate this type of cumulative distribution, an example for the spray mode rupture rate cumulative distribution for a fire protection pipe (0 to 4" in diameter) is shown below in Figure 1.

Figure 1: Example of Pipe Rupture Rate Cumulative Distribution



To investigate the uncertainty associated with estimating both pipe diameters and lengths obtained during walkdowns, an uncertainty distribution was created around those recorded estimates in which a triangular distribution was created with minimum, most likely and maximum values. That is, the recorded values obtained during walkdowns were viewed as the most likely values, but a minimum and maximum value were postulated based on arbitrary scaling factors for the diameter and pipe lengths recorded from field data. For the minimum pipe diameter estimate, the recorded value from the field was multiplied by a scaling factor of 0.7, and the maximum value was computed by multiplying the field data by a factor of 1.5. For pipe length estimates, the chosen factors were chosen so as to account for a wider range of uncertainty in estimating pipe lengths, e.g., large open areas with long pipe runs in the overhead made obtaining accurate field estimates difficult. The minimum value for pipe lengths was obtained by multiplying the recorded estimate by a factor of 0.5, and the maximum value computed by multiplying the field value estimate by a factor of two, which captures the remote possibility that an identical length of pipe was somehow overlooked during plant walkdowns. To simulate this, the pipe diameter and length estimates were replaced with the @RISK spreadsheet function RiskTriang(min, m.likely, max) where "min" represented the calculated minimum diameter or length, the placeholder "m.likely" was the estimate recorded in the field, and "max" was the maximum calculated diameter or length estimate. To illustrate this concept, a plot of the triangular distributions for pipe diameter and length estimates is depicted below in Figures 2a and 2b.

Figure 2a: Likelihood Distribution for Pipe Diameter Estimation

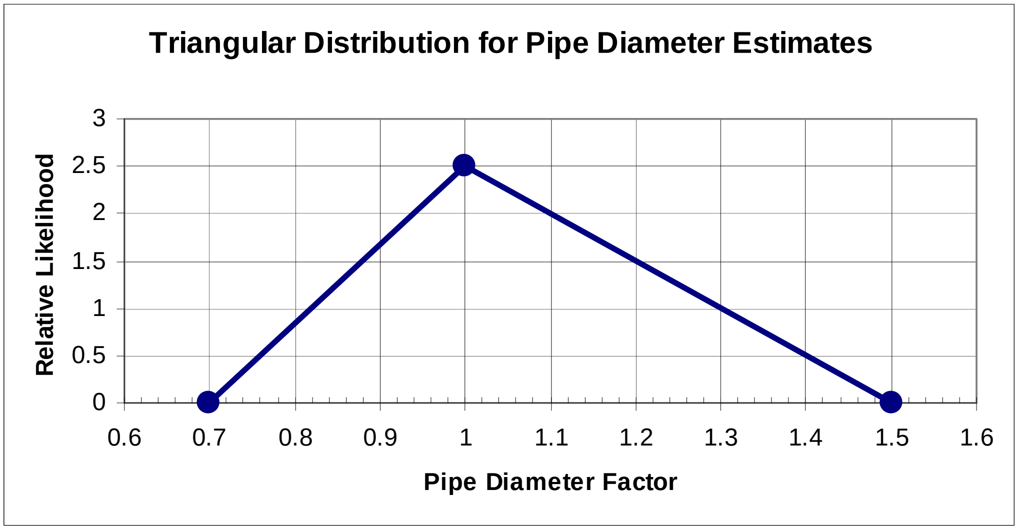
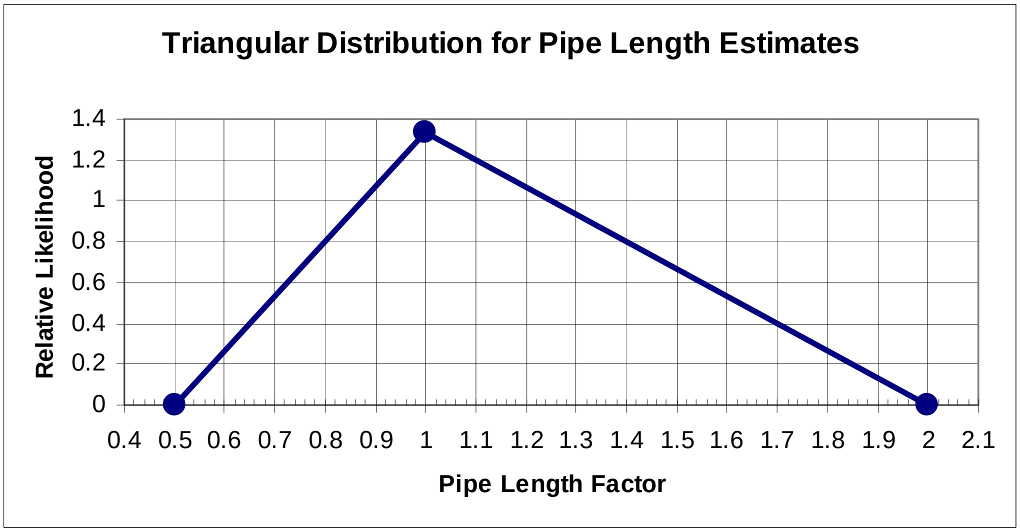


Figure 2b: Likelihood Distribution for Pipe Length Estimation



3. PARAMETRIC UNCERTAINTY RESULTS

Based on the above probability distributions for pipe rupture frequencies and the uncertainty associated with data gathered in the field during plant walkdowns, an @RISK simulation using the Latin Hypercube sampling algorithm with 10,000 iterations was performed to construct a probability distribution for each of the individual internal flood scenarios described above in Section 2.2, i.e., FLOOD-01-SPR, FLOOD-01-FLD, FLOOD-01-MAJ, etc. The resulting probability distributions from this simulation are described in Table 3, which shows the resulting percentiles and other statistical parameters for each modeled internal flood initiator.

Table 3: Internal Flood Scenario Simulated Statistics

Scenario Description	Mean	Variance	5th Percentile	50th Percentile	95th Percentile
FLOOD-01-SPR	4.96E-04	5.68E-08	1.93E-04	4.48E-04	9.64E-04
FLOOD-01-FLD	8.02E-05	2.21E-09	2.27E-05	6.93E-05	1.72E-04
FLOOD-01-MAJ	6.71E-06	7.54E-11	1.08E-07	2.59E-06	2.61E-05
FLOOD-02-SPR	1.05E-04	1.70E-08	5.61E-07	8.75E-06	3.64E-04
FLOOD-02-FLD	3.87E-06	1.16E-11	1.60E-07	2.31E-06	1.02E-05
FLOOD-02-MAJ	2.98E-07	7.13E-14	1.17E-08	1.74E-07	8.06E-07
FLOOD-03-SPR	4.15E-05	1.05E-09	5.23E-06	3.22E-05	1.04E-04
FLOOD-03-FLD	2.22E-05	3.04E-10	2.54E-06	1.57E-05	5.50E-05
FLOOD-03-MAJ	2.07E-05	2.15E-10	3.09E-06	1.62E-05	4.80E-05

A depiction of the graphical results of a resultant uncertainty distribution for scenario FLOOD-01-FLD (general flooding mode of water sources associated with scenario FLOOD-01) is presented below in Figure 3. The abscissa represents the frequency per year for a general flooding event, while the ordinate represents the normalized relative likelihood such that the total area under the curve represents a value of unity. To fit the graphical results to a more manageable and continuous distribution, the gamma distribution was chosen as the basis for modeling the resultant distributions. To define the gamma distribution, the shape parameter α and scale parameter, which is defined as $1/\beta$, were determined based on mathematical definitions using the mean and variance from the resultant @RISK distributions reported in Table 3. That is, the parameter α is derived from the square of the mean divided by the variance, and β is found from the mean divided by the variance. Since β can be viewed as having "pseudo time units," the scale parameter is defined as the reciprocal of β—i.e., an estimate of the mean for the gamma distribution is derived as the number of failures (α) divided by the time interval (β), or α/β [3]. The α and β factors of a postulated gamma distribution for each scenario listed in Table 3 are calculated in Table 4. From Ref. [3], the defining equation for the continuous gamma distribution is given below in Eq. (2). The modeled continuous gamma distribution for FLOOD-01-FLD is depicted in Figure 4, which shows close agreement to the resultant @RISK uncertainty distribution shown in Figure 3.

$$f(\lambda) = \frac{\beta^{\alpha}\,\lambda^{\alpha-1}}{\Gamma(\alpha)}\,e^{-\beta\cdot\lambda} \tag{2}$$

Table 4: Derived Gamma Distribution Parameters

Scenario Description	Gamma Distribution α Factor	Gamma Distribution β Factor
FLOOD-01-SPR	4.34	8.74E+03
FLOOD-01-FLD	2.91	3.63E+04
FLOOD-01-MAJ	0.60	8.91E+04
FLOOD-02-SPR	0.65	6.18E+03
FLOOD-02-FLD	1.29	3.34E+05
FLOOD-02-MAJ	1.24	4.17E+06
FLOOD-03-SPR	1.65	3.96E+04
FLOOD-03-FLD	1.62	7.29E+04
FLOOD-03-MAJ	1.99	9.62E+04

Figure 3: Resultant Distribution from @RISK for Scenario FLOOD-01-FLD

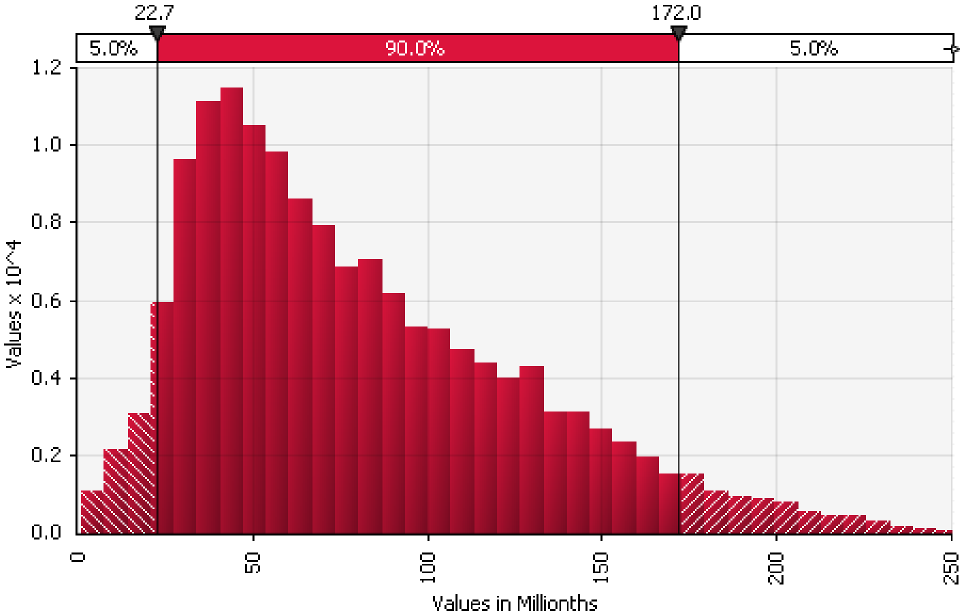
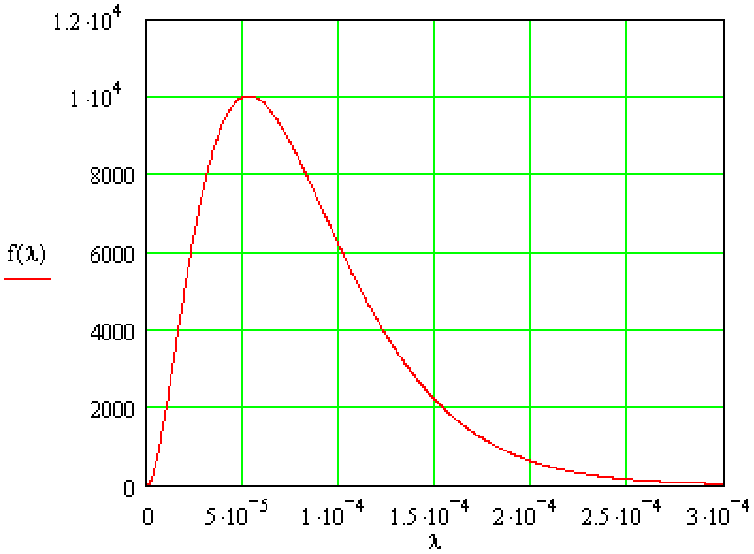


Figure 4: Representative Gamma Distribution for Scenario FLOOD-01-FLD



4. CONCLUSION

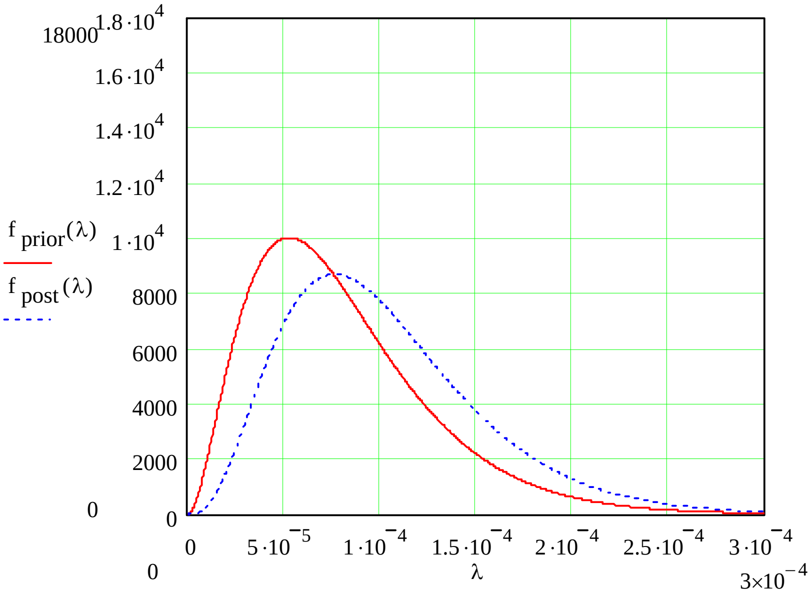
The methodology described above provides the ability to take into account both industry-wide data and inherent uncertainties associated with plant-specific data gathering activities in the field. Although the described methodology assigned arbitrary distributions to pipe diameter and length estimates, these distributions could be better refined and uncertainties greatly reduced if system schematics and isometric drawings were reviewed. However, this process can be tedious as well as time consuming and also be subject to error. This proposed method of characterizing the uncertainties associated with both industry data and collection of plant-specific information in the field was meant to facilitate other PRA applications and the ability to provide for future Bayesian updating.

As a result of estimating the uncertainty distribution for each of the internal flood initiators as a continuous gamma distribution, the distribution parameters can be easily derived and then serve as an input to PRA databases that utilize this information when performing uncertainty analyses on the Core Damage Frequency (CDF) results from PRA model cutsets.

Additionally, and perhaps more importantly, the ability to model the internal flood initiators as a continuous gamma distribution allows the opportunity to take advantage of recorded operating experience to update the initiating frequencies using the Bayesian process. As an example, take for instance the initiating event FLOOD-01-FLD that was modeled as a gamma distribution in Figure 4 and assume that to be a prior distribution. For hypothetical purposes, assume that light water reactors (LWRs) of a similar design experienced 1 pipe rupture ($s = 1$) for this type of scenario within a time period of 20 operating years for 100 LWRs ($t = 2{,}000$ reactor-years). The Bayesian process and equations described in Ref. [3] show that a posterior distribution can be obtained by defining an updated gamma distribution with $(s + \alpha)$ as the new shape parameter and $1/(t + \beta)$ as the new scale parameter. The defining equation for the posterior distribution is given below in Eq. (3). The posterior distribution is plotted in Figure 5 for comparison purposes with the prior distribution that was previously presented in Figure 4.

$$f_{post}(\lambda) = \frac{(t+\beta)^{(s+\alpha)}}{\Gamma(s+\alpha)} \cdot \lambda^{(s+\alpha)-1} \cdot e^{-(t+\beta)\cdot\lambda} \tag{3}$$

Figure 5: Hypothetical Posterior Distribution for Scenario FLOOD-01-FLD



Finally, NRC Regulatory Guide 1.200 [4] calls for the consideration of uncertainty with regard to various risk-informed applications. Although no particular method is specifically required, the methodology outlined in this paper suggests one means of quantifying and estimating the degree of uncertainty with regard to internal flood events. The parametric uncertainty method described above serves to provide the analyst with flexibility and further insight into the uncertainty associated with both industry failure rate data and plant-specific data gathering techniques for internal flood initiators developed within an internal events PRA model.

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