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Revision 1

Developing Component-Specific Prior Distributions for Common Cause Failure Alpha Factors

January 2023

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ABSTRACT

This report presents the development of component-specific common cause failure (CCF) prior distributions for five component categories: pump, valve, strainer, generator, and other equipment. For ease in comparing these component-specific CCF priors with the 2015 generic CCF priors, the same method used to develop the 2015 generic CCF priors was also employed in this report, along with the same set of failure data (1997–2015) featured in INL/EXT-21-43723. For selected CCF templates, this report also evaluates the effects of applying component-specific priors to CCF parameters.

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ACRONYMS

AFW	auxiliary feedwater
AOV	air-operated valve
BAT	battery
BFR	binomial failure rate
CCCG	common cause component group
CC	fail to open
CCF	common cause failure
CNID	constrained noninformative distribution
DCP	direct current power
EDG	emergency diesel generator
EPS	emergency power system
FR	fail to run
FS	fail to start
FTOC	fail to open/close
INL	Idaho National Laboratory
LP	fail to operate
MDP	motor-driven pump
MLE	maximum likelihood estimator
MOV	motor-operated valve
NRC	U.S. Nuclear Regulatory Commission
PG	plug
PRA	probabilistic risk assessment
RADS	Reliability and Availability Data System
SVV	safety valve (direct acting)
TSA	traveling screen

Developing Component-Specific Prior Distributions for Common Cause Failure Alpha Factors

1. INTRODUCTION

Common cause failures (CCFs) have been recognized as significant risk contributors ever since the early launching of probabilistic risk assessments (PRAs) for commercial nuclear power plants. Since the 1980s, a series of reports (e.g., those pertaining to U.S. Nuclear Regulatory Commission [NRC] research results) have been published to provide guidance on performing CCF modeling using PRA, as well as on conducting CCF event data analysis. These technical reports include NUREG/CR-4780 [1, 2], NUREG/CR-6268 [3, 4, 5, 6], NUREG/CR-5497 [7], NUREG/CR-5485 [8], and NUREG/CR-6268 [9]. A CCF database system was developed and is maintained by NRC and Idaho National Laboratory (INL) for the U.S. commercial nuclear power industry. This CCF database system consists of (1) a CCF database that stores coded CCF events and (2) a CCF software program that applies an impact vector and mapping method to estimate CCF parameters for those coded CCF events. The CCF database has been maintained ever since its development in the late 1990s, and the CCF parameter estimations have been updated and published periodically on the NRC Reactor Operational Experience Results and Databases website (https://nrcoe.inl.gov). The latest update [10] uses the most recent 15-year dataset, which spans the period of 2006–2020.

CCF parameters are estimated using a Bayesian update method. New evidence (i.e., new CCF event occurrences) from the nuclear power industry is usually sparse; hence, the selection of priors can strongly influence posteriors (i.e., CCF parameter estimates). Prior distributions are either based on analysts' subjective judgement or on the observed data. In [8], several approaches for developing CCF prior distributions are described, based on observed data collected across all components and failure modes—without involving detailed descriptions of the prior-distribution-developing processes. Various generic prior distributions (or simply "prior distributions" or "priors") were developed in the early 2000s by applying different date ranges of then-available failure data to CCF alpha factor model parameter estimations [11]. In [12], generic prior distributions for CCF alpha factors were updated using the failure data from 1997–2015, which were the most recent data available at the time the report was written. That report presented a process for developing CCF prior distributions, and used it to update the generic CCF priors on the 1997–2015 dataset. These 2015 generic priors have been used in the 2020 CCF parameter estimations [10].

Besides using the same generic priors to estimate all CCF parameters, an alternative approach is to partition the raw data into smaller pools (e.g., by failure cause, component type, or failure mode), then use the data in each pool to develop pool-specific priors in order to better represent pool-specific performance and so reduce the uncertainties caused by pool-to-pool variabilities. For example, in [12], five sets of causal CCF priors (i.e., for the following failure cause groups: component, design, environment, human, and "other") were also developed using the 1997–2015 dataset. These 2015 causal CCF priors were utilized to develop 2020 causal CCF parameter estimates [13]. The causal CCF parameter estimations can be applied to the causal alpha factor model, as was examined in [14]. Also, during development of the 2015 generic CCF priors in [12], it was found that different component types could have drastically different alpha factors and should thus be analyzed separately.

1.1 Task Overview

This study aims to develop component-type-specific (i.e., component-specific) priors and then compare them to the current alpha factors as described in [15]. This study consists of four work areas: (1) determine specific component types and failure modes for the case study; (2) develop component-specific priors for the selected component types; (3) estimate CCF parameters for selected component failure modes, using the new component-specific priors; and (4) compare the CCF parameters that use component-specific priors to those that use generic priors. This report presents the results for five component-specific CCF prior distributions for component categories: pump, valve, strainer, generator, and “other”. For ease in comparing the results of the component-specific priors and the 2015 generic priors, the same method employed in developing the 2015 generic priors was used, along with the same set of failure data (1997–2015) utilized in [12]. This report also uses the component-specific CCF priors to estimate CCF parameters for select component failure modes, and it compares these parameter estimates against those derived using generic priors.

1.2 Method

This section summarizes the method of developing component-specific prior distributions. An existing method was employed to develop prior distributions for alpha factors pertaining to each common cause component group (CCCG) size, utilizing all CCF events in the CCF database. This method was used in [12] to update generic priors and is adopted in this study to develop component-specific priors. For the sake of completeness, a brief summary of this method is given below.

In this method, CCF events are first separated into complete CCF events and partial CCF events. A complete CCF is one in which all redundant components simultaneously fail as a direct result of a shared cause (i.e., the component degradation value equals 1.0 for all components, and both the timing and shared cause factors equal 1.0). A partial CCF is one that features at least one character parameter (component degradation value, timing factor, or shared cause factor) that does not equal 1.0. Each CCF event is then mapped from its original CCCG size to a given target CCCG size via one of two approaches: for partial CCF events, the mapping is done by adjusting their impact vectors; for complete CCF events, a binomial regression approach is used to curve fit and determine the mathematical relationship between CCCG size and the number of complete CCF events.

Each alpha factor has its own beta distribution, and all alpha factors within the same CCCG are bounded under the same Dirichlet distribution. The maximum likelihood estimator (MLE) for each alpha factor is first calculated based on the mapped CCF events. This MLE is then used to obtain the beta distribution for the given alpha factor via a constrained noninformative distribution (CNID). Finally, all alpha factors within the same CCCG are combined to calculate the Dirichlet distribution parameters. APPENDIX A of this report provides mathematical background information on Dirichlet distributions and explores how an appropriate noninformative Dirichlet distribution can be determined. It also includes a section on generating random samples from a Dirichlet distribution, and examines an example case in detail.

The methodological steps in this method are summarized as follows:

Step 1. For each CCCG size, tabulate the number of partial CCF events and complete CCF events.

Step 2. Calculate the n_k values for each group size (2–16), using all partial (i.e., incomplete) CCF events. This involves mapping both up and down.

Step 3. Using the information obtained in Step 1, perform a binomial regression to obtain the probability of complete CCF events for a given group size.

Step 4. For each CCF group size, use the results from Step 3 to obtain the estimated number of complete CCF events. Add this number to the n_k (from Step 2), which corresponds to simultaneous failures of all the components. For example, for a group size of 2, add the number to n_2; for a group size of 4, add it to n_4.

Step 5. Using the final n_k values from Step 4, estimate the mean value alpha factors for each group size.

Step 6. Using the final n_k values, estimate the beta prior distributions for each group size. The parameters of the beta distribution are α and β. The beta distribution is denoted by Beta(α, β). INL developed a computer code, CalcPrior, to estimate the beta prior distributions via a procedure for calculating Dirichlet distribution parameters by employing noninformative prior distributions.

Step 7. As a check, calculate the mean of each prior distribution and compare them with the values obtained in Step 5. The mean value is obtained via the formula $\mu = \alpha / (\alpha+\beta)$.

1.3 Outline

The remainder of this report is organized as follows. Section 2 presents the component type categorization used for developing component-specific priors. Sections 3–7 present the development of CCF prior distributions specific to five component types: pump, valve, strainer, generator, and other. Three component types (i.e., pump, valve, and other) entail lethal shock events, and the sections corresponding to these types (i.e., Sections 3, 4, and 7) include a sensitivity study subsection that examines the impacts of using different approaches to count lethal shocks. Section 8 presents the CCF parameter posterior estimation process, which involves using component-specific priors for selected CCF templates across the five component types. Section 9 provides the results of the component-specific priors and posteriors, and presents the conclusions reached over the course of this study. APPENDIX A, written by Dr. C. Atwood, provides background information on the Dirichlet distribution used in the CCF parameter estimations. This distribution has been mentioned (but not described in detail) in previous CCF reports such as [8] and [12].

2. COMPONENT TYPE CATEGORIZATION

This section presents the component type categorization used for developing component-specific priors. During the development of the 2015 generic CCF priors [12], it was found that different component types could have drastically different alpha factors and should thus be analyzed separately. Although it is possible to include any component type in the analysis, to produce statistically valid conclusions the components should not be divided too finely into small classes. Therefore, it is recommended that they be grouped according to the most common component types (i.e., the pump, valve, strainer, and generator categories), with the less common types being lumped into the "other" category. This resulted in the following list: pump, valve, strainer, generator, and other. Table 2-1 presents the relationships between these five component types and the complete set of component types in the NRC Reliability and Availability Data System (RADS). Note that RADS contains more component types than are shown in the table, as this table only includes the RADS component types for which CCF events have occurred. The component types listed in this table correspond to the 269 CCF events[1] used in this study (events that occurred between 1997 and 2015 and had a group size of between 2 and 16), with the events that occurred in setpoint failure mode being excluded.

Table 2-1. Component types used in this study and those in NRC RADS.

Component Types for Component-Specific Prior Development	Number of CCF Events	Component Type Used in NRC RADS			Number of CCF Events
		Broad Type	Specific Type		
Pump	47	Pump	MDP	motor-driven pump	45
			TDP	turbine-driven pump	2
Valve	123	Valve	AOV	air-operated valve	23
			CKV	check valve	9
			HOV	hydraulic-operated valve	1
			MOV	motor-operated valve	14
			MSV	main steam stop valve	39
			PRV	power-operated relief valve	15
			RVL	low-capacity relief valve	6
			SRV	safety relief valve (dual activation)	15
			SVV	safety valve (single acting)	4
Strainer	51	Filter	STR	strainer	51
Generator	15	Emergency Power	GEN	generator	15
Other	33	Electrical	BAT	battery	1
			BCH	battery charger	9
			CRB	circuit breaker	12
			TFM	transformer	1
		Other	CMP	compressor	6
			HTX	heat exchanger	2
			VAC	vacuum breaker valve	2
Total No. of CCF Events: 269					

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[1] Note that the specific failure event counts in this report may differ slightly from those in INL/EXT-21-43723 [12], due to the potential event reclassification and/or new events added to the CCF database.

3. DEVELOPING PRIOR DISTRIBUTIONS OF ALPHA FACTORS SPECIFIC TO PUMP COMPONENTS

This section presents the development of the prior distributions of alpha factors specific to pump components.

3.1 Accessing CCF Data

To estimate the prior distributions for the pump component type, the following selection criteria are defined on the NRC RADS CCF database website (https://rads.inl.gov/Pages/CCF.aspx)[2]:

- Type of CCF Event Level: All Level CCF Events
- CCF Event Type: CCF Events Only
- Date Range: 1997–2015
- Filter Independent Events by Selected Cause(s): True
- Shock Criteria: All Events
- Redundancy Range: Minimum = 2, Maximum = 16
- Bayesian Update Method: Mean Method
- Failure Modes: select all failure modes except Setpoint
- CCF Categories: Components → Pump.

A total of 47 CCF events and 1,906.0 effective independent failure events related to the above selection criteria. The additional criterion of CCF Categories → Degree → Almost/Partial or Complete was applied to obtain the number of partial/complete CCF events, as required in the existing process. The unmapped and mapped impact vectors were also acquired from the CCF database website. The mapped impact vectors for partial CCF events pertaining to each group size, as obtained from the website, were used directly in the study. Table 3-1 shows the number of partial CCF events, the number of complete CCF events, and the total number of CCF events. Table 3-2 shows the mapped impact vectors for partial CCF events pertaining to each group size (2–16), as obtained from the CCF database website.

Table 3-1. CCF data (pump).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events
2	10	7	17
3	10	2	12
4	14	0	14
5	1	0	1
6	2	0	2
7	0	0	0
8	1	0	1
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0

---

[2] The NRC RADS CCF database system includes proprietary information and is unavailable to the public.

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
Total	38	9	47

Table 3-2. n_k values for partial CCF events (pump).

Group Size	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	28.12	6.827	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	26.62	15.563	1.639	—	—	—	—	—	—	—	—	—	—	—	—	—
4	23.96	19.400	5.727	0.730	—	—	—	—	—	—	—	—	—	—	—	—
5	25.50	16.408	9.359	3.247	0.399	—	—	—	—	—	—	—	—	—	—	—
6	26.75	14.616	10.487	5.370	1.925	0.224	—	—	—	—	—	—	—	—	—	—
7	27.88	13.514	10.473	6.809	3.378	1.169	0.128	—	—	—	—	—	—	—	—	—
8	28.86	12.952	10.004	7.551	4.573	2.225	0.722	0.075	—	—	—	—	—	—	—	—
9	29.71	12.731	9.451	7.762	5.434	3.180	1.497	0.453	0.045	—	—	—	—	—	—	—
10	30.45	12.720	8.976	7.647	5.950	3.966	2.263	1.019	0.287	0.0273	—	—	—	—	—	—
11	31.10	12.831	8.628	7.375	6.172	4.551	2.943	1.631	0.699	0.1849	0.0169	—	—	—	—	—
12	31.68	13.006	8.407	7.060	6.177	4.929	3.504	2.210	1.184	0.4832	0.1204	0.0106	—	—	—	—
13	32.20	13.211	8.290	6.770	6.049	5.124	3.929	2.720	1.671	0.8640	0.3361	0.0792	0.0068	—	—	—
14	32.67	13.427	8.251	6.535	5.853	5.172	4.218	3.143	2.124	1.2693	0.6333	0.2352	0.0526	0.0043	—	—
15	33.09	13.642	8.263	6.363	5.640	5.118	4.382	3.467	2.523	1.6644	0.9675	0.4662	0.1656	0.0352	0.0028	—
16	33.48	13.852	8.309	6.250	5.440	5.000	4.443	3.692	2.853	2.0294	1.3070	0.7399	0.3446	0.1171	0.0237	0.0018

3.2 Treating Complete CCF Events

This study uses the same binomial regression method as in [12] to curve fit the fraction of complete CCF events over the total number of CCF events. This binomial regression defines *P(m)* as the probability of a CCF event being a complete failure in a particular group size, *m*. It then uses the observed fractions of complete CCF failures in all group sizes and fits the data via a predefined function. In this study, Microsoft Excel [16] was used for the curve fitting. Similar to the curve fitting in [12], the following function, rather than the general logit function $\ln\left(\frac{P(m)}{1-P(m)}\right) = a + bm$ suggested in [17], was used to fit the curve:

$$\ln\left(\frac{P(m)}{1 - P(m)}\right) = a + b(1 - e^{-m}) \qquad (1)$$

Note that, in previous work on developing generic priors [12], the binomial regression treatment of complete CCF events did not distinguish lethal shock events from non-lethal-shock-but-complete-CCF events. For lethal shocks, the impact vector is supposed to map directly (i.e., the probability of all x components in a system of x components having failed due to lethal shock is mapped directly and equals the probability of failing all y components in a system of y components). Hence, the correct process should treat lethal shock events differently from non-lethal-shock-but-complete-CCF events (i.e., the lethal shock events should be removed from the curve-fitting process [do not include the lethal shock events in the No. Complete CCF Events category]); instead, the total number of lethal shock events, without regard to their group sizes, should be added to the final n_k values of each group size.

While this report follows the same approach used in [12] so as to not distinguish lethal shocks, sensitivity analyses of the applicable component types were conducted to examine the impact of distinguishing lethal shocks (i.e., excluding lethal shocks from the binomial regression and adding the total number of lethal shocks to the final n_k values). A review of the pump CCF data used in this study (i.e., 1997–2015, excluding setpoint failure mode) found only one CCF event coded as a lethal shock: 263-1999-0046, corresponding to a group size of 2. The results (i.e., the probability of a complete CCF event and the estimated number of complete CCF events for each group size) when not distinguishing lethal shocks are listed in the last two columns of Table 3-3. The sensitivity analysis results when distinguishing lethal shocks are presented in Section 3.4.

Table 3-3. CCF data with curve-fitted complete CCF events (pump).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events	Prob. of Complete CCF Event - Data	Prob. of Complete CCF Event - Curve Fitting	Estimated No. Complete CCF Events
2	10	7	17	0.412	0.412	6.998
3	10	2	12	0.167	0.167	1.999
4	14	0	14	0.000	0.112	1.568
5	1	0	1	0.000	0.096	0.096
6	2	0	2	0.000	0.091	0.182
7	0	0	0	NA	0.089	0.000
8	1	0	1	0.000	0.088	0.088
9	0	0	0	NA	0.088	0.000
10	0	0	0	NA	0.088	0.000
11	0	0	0	NA	0.088	0.000
12	0	0	0	NA	0.088	0.000
13	0	0	0	NA	0.088	0.000
14	0	0	0	NA	0.088	0.000
15	0	0	0	NA	0.088	0.000
16	0	0	0	NA	0.088	0.000
Total	38	9	47	—	—	10.931[a]

Note: There is a discrepancy between the number of complete CCF events estimated based on the binomial regression and the actual number of complete CCF events (i.e., 10.931 vs. 9). This discrepancy is expected, since the number of data points for the binomial regression is very low (i.e., two). Some data points were discarded because either the total CCF event number or complete CCF event number was zero. This same issue exists for the remaining analyses covered in this report.

3.3 Estimating Prior Distributions

Adjusted n_k values for pump CCF events were obtained for each group size by adding the estimated number of complete CCF events in Table 3-3 to the final n_k value for the partial CCF events in Table 3-2. For example, in Table 3-3, the estimated number of complete CCF events for a group size of 2 is 6.998; in Table 3-2, the n_2 value for partial CCF events for a group size of 2 is 6.827. Thus, the adjusted n_2 value for a group size of 2 will be 6.998 + 6.827 = 13.825. Table 3-4 shows the adjusted n_k results of the pump CCF data for group sizes 2–16. The adjusted independent failure event counts (n_I), as obtained from the CCF database website, and the total number of failures (n_t) (i.e., the sum of n_I and n_k, k = 1 to 16) for each group size are presented in the table. The MLEs—later used as mean values for beta distributions—of the alpha factors for each group size can then be calculated using Eqs. (2) and (3) below. The results are presented in Table 3-5.

$$\alpha_1 = \frac{n_I + n_1}{n_t} \tag{2}$$

$$\alpha_i = \frac{n_i}{n_t}, for\ i\ =\ 2, \dots, m \tag{3}$$

Adjusted n_k and n_I values were input to the computer code CalcPrior to estimate the industry-wide prior distributions with parameters α and β. The CalcPrior code was developed in early 2000, then recoded in modern computer language for [12].

Figure 3-1, printed below, shows the code's needed input for calculating the prior distributions. Such input includes the prior name, unadjusted independent event count (called the "effective independent event count" on the CCF database website, and shown as "Independent Event Count" in Figure 3-1), average CCCG size, description of the prior, and adjusted n_k values for each group size. The average CCCG size (*AVG*) can be calculated from CCF event raw data; but if both the adjusted and unadjusted independent event counts can be obtained from the CCF database website, *AVG* can also be calculated by applying Eq. (4) as follows:

$$AVG = \frac{N * m}{n_I} \tag{4}$$

where n_I = adjusted independent event count for group size *m*

N = unadjusted independent event count

m = group size

These values can be input to the CalcPrior code via the following *.csv* file format:

PriorName, PriorDescription,,,,,,,,,,,,,

TotalIndependentEventCount, AverageGroupSize,,,,,,,,,,,,,

n_1, n_2,,,,,,,,,,,,,

n_1, n_2, n_3,,,,,,,,,,,,

n_1, n_2, n_3, n_4,,,,,,,,,,,

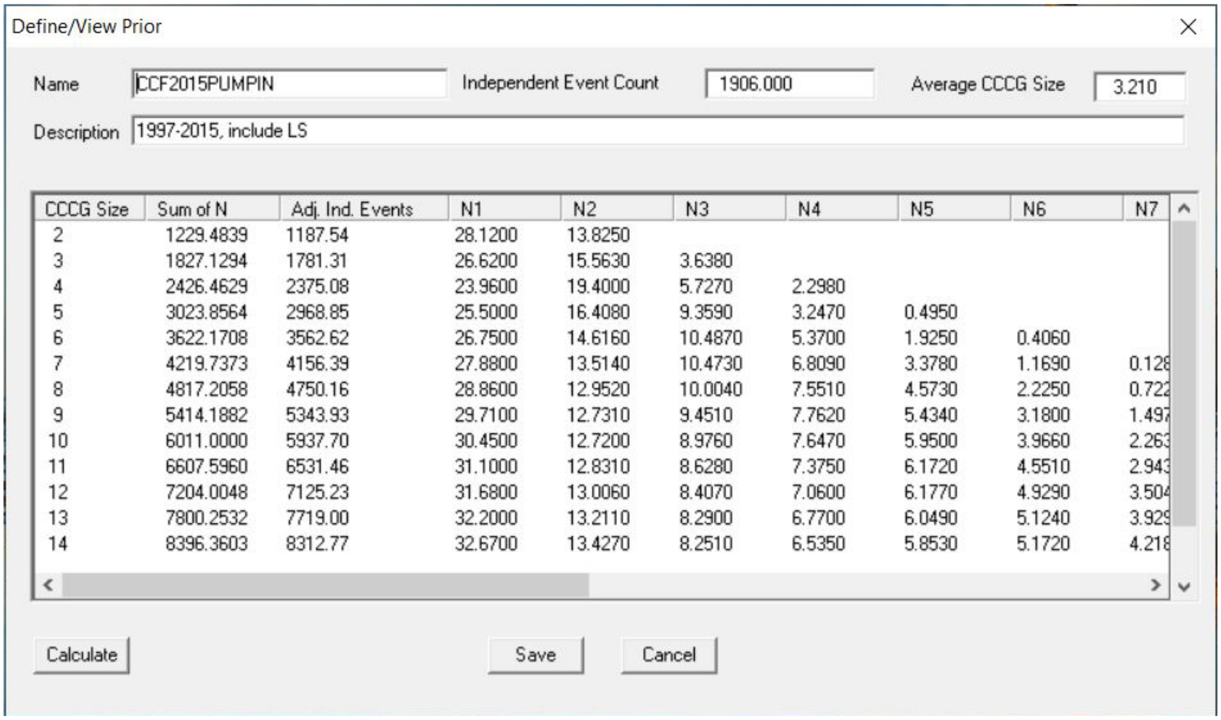
The code will automatically calculate the nI (shown as "Adj. Ind. Events" in Figure 3-1) and nt (shown as "Sum of N" in Figure 3-1) values for each group size, in accordance with the input values. The code can then estimate prior distributions, based on the constrained noninformative and Dirichlet methodology (refer to [17]). Figure 3-2 shows the CalcPrior code results for the prior distribution parameters, and these results were output to Table 3-6. For more details, see APPENDIX A.

Table 3-4. Adjusted n_k values for all CCF events (pump).

Group Size	n_t	n_I	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	1228.47	1186.52	28.12	13.825	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	1825.59	1779.77	26.62	15.563	3.638	—	—	—	—	—	—	—	—	—	—	—	—	—
4	2424.42	2373.03	23.96	19.400	5.727	2.298	—	—	—	—	—	—	—	—	—	—	—	—
5	3021.30	2966.29	25.50	16.408	9.359	3.247	0.495	—	—	—	—	—	—	—	—	—	—	—
6	3619.10	3559.55	26.75	14.616	10.487	5.370	1.925	0.406	—	—	—	—	—	—	—	—	—	—
7	4216.16	4152.81	27.88	13.514	10.473	6.809	3.378	1.169	0.128	—	—	—	—	—	—	—	—	—
8	4813.12	4746.07	28.86	12.952	10.004	7.551	4.573	2.225	0.722	0.163	—	—	—	—	—	—	—	—
9	5409.58	5339.32	29.71	12.731	9.451	7.762	5.434	3.180	1.497	0.453	0.045	—	—	—	—	—	—	—
10	6005.89	5932.58	30.45	12.720	8.976	7.647	5.950	3.966	2.263	1.019	0.287	0.0273	—	—	—	—	—	—
11	6601.97	6525.84	31.10	12.831	8.628	7.375	6.172	4.551	2.943	1.631	0.699	0.1849	0.0169	—	—	—	—	—
12	7197.87	7119.10	31.68	13.006	8.407	7.060	6.177	4.929	3.504	2.210	1.184	0.4832	0.1204	0.0106	—	—	—	—
13	7793.61	7712.36	32.20	13.211	8.290	6.770	6.049	5.124	3.929	2.720	1.671	0.8640	0.3361	0.0792	0.0068	—	—	—
14	8389.20	8305.61	32.67	13.427	8.251	6.535	5.853	5.172	4.218	3.143	2.124	1.2693	0.6333	0.2352	0.0526	0.0043	—	—
15	8984.66	8898.87	33.09	13.642	8.263	6.363	5.640	5.118	4.382	3.467	2.523	1.6644	0.9675	0.4662	0.1656	0.0352	0.0028	—
16	9580.01	9492.13	33.48	13.852	8.309	6.250	5.440	5.000	4.443	3.692	2.853	2.0294	1.3070	0.7399	0.3446	0.1171	0.0237	0.0018

Table 3-5. Calculated alpha factor mean values (pump).

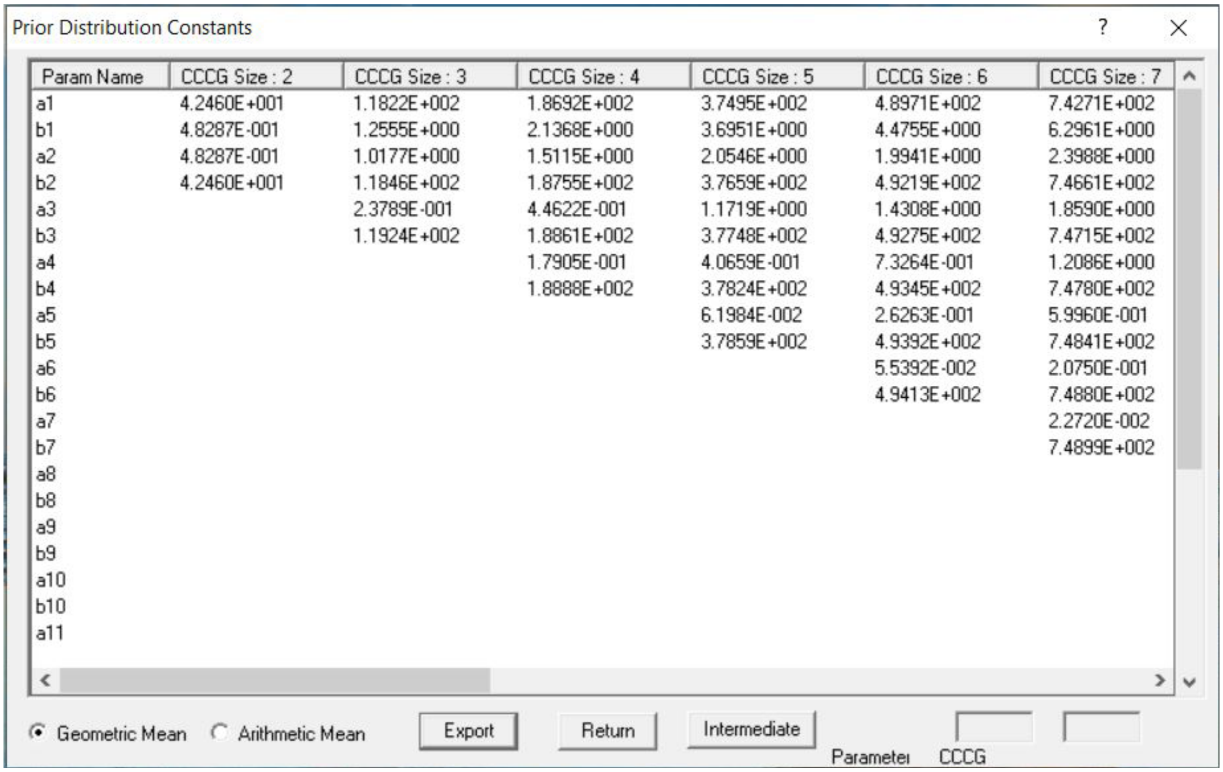
Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9887	1.125E-02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9895	8.525E-03	1.993E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9887	8.002E-03	2.362E-03	9.479E-04	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9902	5.431E-03	3.098E-03	1.075E-03	1.638E-04	—	—	—	—	—	—	—	—	—	—	—
6	0.9909	4.039E-03	2.898E-03	1.484E-03	5.319E-04	1.122E-04	—	—	—	—	—	—	—	—	—	—
7	0.9916	3.205E-03	2.484E-03	1.615E-03	8.012E-04	2.773E-04	3.036E-05		—	—	—	—	—	—	—	—
8	0.9921	2.691E-03	2.078E-03	1.569E-03	9.501E-04	4.623E-04	1.500E-04	3.387E-05	—	—	—	—	—	—	—	—
9	0.9925	2.353E-03	1.747E-03	1.435E-03	1.005E-03	5.878E-04	2.767E-04	8.374E-05	8.319E-06	—	—	—	—	—	—	—
10	0.9929	2.118E-03	1.495E-03	1.273E-03	9.907E-04	6.604E-04	3.768E-04	1.697E-04	4.779E-05	4.546E-06	—	—	—	—	—	—
11	0.9932	1.944E-03	1.307E-03	1.117E-03	9.349E-04	6.893E-04	4.458E-04	2.470E-04	1.059E-04	2.801E-05	2.560E-06	—	—	—	—	—
12	0.9935	1.807E-03	1.168E-03	9.808E-04	8.582E-04	6.848E-04	4.868E-04	3.070E-04	1.645E-04	6.713E-05	1.673E-05	1.473E-06	—	—	—	—
13	0.9937	1.695E-03	1.064E-03	8.687E-04	7.761E-04	6.575E-04	5.041E-04	3.490E-04	2.144E-04	1.109E-04	4.313E-05	1.016E-05	8.725E-07	—	—	—
14	0.9939	1.601E-03	9.835E-04	7.790E-04	6.977E-04	6.165E-04	5.028E-04	3.746E-04	2.532E-04	1.513E-04	7.549E-05	2.804E-05	6.270E-06	5.126E-07	—	—
15	0.9941	1.518E-03	9.197E-04	7.082E-04	6.277E-04	5.696E-04	4.877E-04	3.859E-04	2.808E-04	1.852E-04	1.077E-04	5.189E-05	1.843E-05	3.918E-06	3.116E-07	—
16	0.9943	1.446E-03	8.673E-04	6.524E-04	5.678E-04	5.219E-04	4.638E-04	3.854E-04	2.978E-04	2.118E-04	1.364E-04	7.723E-05	3.597E-05	1.222E-05	2.474E-06	1.879E-07



Name: CCF2015PUMPIN
Independent Event Count: 1906.000
Average CCCG Size: 3.210
Description: 1997-2015, include LS

CCCG Size	Sum of N	Adj. Ind. Events	N1	N2	N3	N4	N5	N6	N7
2	1229.4839	1187.54	28.1200	13.8250					
3	1827.1294	1781.31	26.6200	15.5630	3.6380				
4	2426.4629	2375.08	23.9600	19.4000	5.7270	2.2980			
5	3023.8564	2968.85	25.5000	16.4080	9.3590	3.2470	0.4950		
6	3622.1708	3562.62	26.7500	14.6160	10.4870	5.3700	1.9250	0.4060	
7	4219.7373	4156.39	27.8800	13.5140	10.4730	6.8090	3.3780	1.1690	0.128
8	4817.2058	4750.16	28.8600	12.9520	10.0040	7.5510	4.5730	2.2250	0.722
9	5414.1882	5343.93	29.7100	12.7310	9.4510	7.7620	5.4340	3.1800	1.497
10	6011.0000	5937.70	30.4500	12.7200	8.9760	7.6470	5.9500	3.9660	2.263
11	6607.5960	6531.46	31.1000	12.8310	8.6280	7.3750	6.1720	4.5510	2.943
12	7204.0048	7125.23	31.6800	13.0060	8.4070	7.0600	6.1770	4.9290	3.504
13	7800.2532	7719.00	32.2000	13.2110	8.2900	6.7700	6.0490	5.1240	3.929
14	8396.3603	8312.77	32.6700	13.4270	8.2510	6.5350	5.8530	5.1720	4.218

Figure 3-1. Input to the CalcPrior code for estimating CCF prior distributions (pump).



Param Name	CCCG Size : 2	CCCG Size : 3	CCCG Size : 4	CCCG Size : 5	CCCG Size : 6	CCCG Size : 7
a1	4.2460E+001	1.1822E+002	1.8692E+002	3.7495E+002	4.8971E+002	7.4271E+002
b1	4.8287E-001	1.2555E+000	2.1368E+000	3.6951E+000	4.4755E+000	6.2961E+000
a2	4.8287E-001	1.0177E+000	1.5115E+000	2.0546E+000	1.9941E+000	2.3988E+000
b2	4.2460E+001	1.1846E+002	1.8755E+002	3.7659E+002	4.9219E+002	7.4661E+002
a3		2.3789E-001	4.4622E-001	1.1719E+000	1.4308E+000	1.8590E+000
b3		1.1924E+002	1.8861E+002	3.7748E+002	4.9275E+002	7.4715E+002
a4			1.7905E-001	4.0659E-001	7.3264E-001	1.2086E+000
b4			1.8888E+002	3.7824E+002	4.9345E+002	7.4780E+002
a5				6.1984E-002	2.6263E-001	5.9960E-001
b5				3.7859E+002	4.9392E+002	7.4841E+002
a6					5.5392E-002	2.0750E-001
b6					4.9413E+002	7.4880E+002
a7						2.2720E-002
b7						7.4899E+002
a8						
b8						
a9						
b9						
a10						
b10						
a11						

Figure 3-2. CCF prior distribution parameters calculated by the CalcPrior code (pump).

Table 3-6. Estimated industry-wide alpha factor prior distributions (pump).

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	4.25E+01	4.83E-01	4.83E-01	4.25E+01	—	—	—	—	—	—	—	—	—	—	—	—
3	1.18E+02	1.26E+00	1.02E+00	1.18E+02	2.38E-01	1.19E+02	—	—	—	—	—	—	—	—	—	—
4	1.87E+02	2.14E+00	1.51E+00	1.88E+02	4.46E-01	1.89E+02	1.79E-01	1.89E+02	—	—	—	—	—	—	—	—
5	3.75E+02	3.70E+00	2.05E+00	3.77E+02	1.17E+00	3.77E+02	4.07E-01	3.78E+02	6.20E-02	3.79E+02	—	—	—	—	—	—
6	4.90E+02	4.48E+00	1.99E+00	4.92E+02	1.43E+00	4.93E+02	7.33E-01	4.93E+02	2.63E-01	4.94E+02	5.54E-02	4.94E+02	—	—	—	—
7	7.43E+02	6.30E+00	2.40E+00	7.47E+02	1.86E+00	7.47E+02	1.21E+00	7.48E+02	6.00E-01	7.48E+02	2.08E-01	7.49E+02	2.27E-02	7.49E+02	—	—
8	8.68E+02	6.94E+00	2.35E+00	8.72E+02	1.82E+00	8.73E+02	1.37E+00	8.73E+02	8.30E-01	8.74E+02	4.04E-01	8.74E+02	1.31E-01	8.75E+02	2.96E-02	8.75E+02
9	1.23E+03	9.32E+00	2.92E+00	1.24E+03	2.17E+00	1.24E+03	1.78E+00	1.24E+03	1.25E+00	1.24E+03	7.31E-01	1.24E+03	3.44E-01	1.24E+03	1.04E-01	1.24E+03
10	1.54E+03	1.11E+01	3.29E+00	1.55E+03	2.32E+00	1.55E+03	1.98E+00	1.55E+03	1.54E+00	1.55E+03	1.02E+00	1.55E+03	5.85E-01	1.55E+03	2.63E-01	1.55E+03
11	1.89E+03	1.30E+01	3.70E+00	1.90E+03	2.49E+00	1.90E+03	2.13E+00	1.90E+03	1.78E+00	1.90E+03	1.31E+00	1.90E+03	8.49E-01	1.90E+03	4.70E-01	1.91E+03
12	2.29E+03	1.51E+01	4.16E+00	2.30E+03	2.69E+00	2.30E+03	2.26E+00	2.30E+03	1.98E+00	2.30E+03	1.58E+00	2.30E+03	1.12E+00	2.30E+03	7.07E-01	2.30E+03
13	2.74E+03	1.73E+01	4.66E+00	2.75E+03	2.93E+00	2.75E+03	2.39E+00	2.75E+03	2.13E+00	2.75E+03	1.81E+00	2.75E+03	1.39E+00	2.75E+03	9.60E-01	2.75E+03
14	3.24E+03	1.98E+01	5.21E+00	3.25E+03	3.20E+00	3.26E+03	2.54E+00	3.26E+03	2.27E+00	3.26E+03	2.01E+00	3.26E+03	1.64E+00	3.26E+03	1.22E+00	3.26E+03
15	3.79E+03	2.24E+01	5.79E+00	3.81E+03	3.51E+00	3.81E+03	2.70E+00	3.81E+03	2.39E+00	3.81E+03	2.17E+00	3.81E+03	1.86E+00	3.82E+03	1.47E+00	3.82E+03
16	4.42E+03	2.52E+01	6.42E+00	4.43E+03	3.85E+00	4.44E+03	2.90E+00	4.44E+03	2.52E+00	4.44E+03	2.32E+00	4.44E+03	2.06E+00	4.44E+03	1.71E+00	4.44E+03

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	1.03E-02	1.24E+03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	7.42E-02	1.55E+03	7.05E-03	1.55E+03	—	—	—	—	—	—	—	—	—	—	—	—
11	2.02E-01	1.91E+03	5.33E-02	1.91E+03	4.87E-03	1.91E+03	—	—	—	—	—	—	—	—	—	—
12	3.79E-01	2.30E+03	1.55E-01	2.31E+03	3.85E-02	2.31E+03	3.39E-03	2.31E+03	—	—	—	—	—	—	—	—
13	5.90E-01	2.75E+03	3.05E-01	2.75E+03	1.19E-01	2.75E+03	2.80E-02	2.75E+03	2.40E-03	2.75E+03	—	—	—	—	—	—
14	8.24E-01	3.26E+03	4.93E-01	3.26E+03	2.46E-01	3.26E+03	9.13E-02	3.26E+03	2.04E-02	3.26E+03	1.67E-03	3.26E+03	—	—	—	—
15	1.07E+00	3.82E+03	7.07E-01	3.82E+03	4.11E-01	3.82E+03	1.98E-01	3.82E+03	7.03E-02	3.82E+03	1.49E-02	3.82E+03	1.19E-03	3.82E+03	—	—
16	1.32E+00	4.44E+03	9.40E-01	4.44E+03	6.05E-01	4.44E+03	3.43E-01	4.44E+03	1.60E-01	4.44E+03	5.42E-02	4.44E+03	1.10E-02	4.44E+03	8.34E-04	4.44E+03

3.4 Sensitivity Study

This section presents the sensitivity study results for pump components when distinguishing the **one pump lethal shock event** from the non-lethal-shock-but-complete-CCF events in Table 3-7 and adding that lethal shock event to the final n_k values of the corresponding group size in Table 3-8. Thus, in Table 3-7, for the group size of 2, the number of complete CCF events with non-lethal shocks is six instead of seven, as there is one lethal shock event. That one lethal shock event is added to the n_m (for the group size of m) values in Table 3-2, along with the new estimated number of complete CCF events (with non-lethal shocks only) in Table 3-7. Now, in Table 3-8, the adjusted n_3 for the group size of 3 is 4.639 instead of 3.638, and the adjusted n_{16} for the group size of 16 is 1.0018 instead of 0.0018 (i.e., the value seen in Table 3-4).

Figure 3-3 and Figure 3-4 show the input to and output from the CalcPrior code, respectively. Table 3-9 presents the alpha factor mean values, and Table 3-10 provides the prior distribution parameters for the sensitivity study.

In comparing the values in Table 3-9 to those in Table 3-5, the estimated alpha factor mean values for α_m in the group size of m would be increased when distinguishing lethal shocks from non-lethal shocks in the analysis (e.g., α_3 in the group size of 3 is increased from 1.99E-3 to 2.54E-3, α_4 in the group size of 4 is increased from 9.48E-4 to 1.39E-3, α_8 in the group size of 8 is increased from 3.39E-5 to 1.93E-4, and α_{16} in the group size of 16 is increased from 1.88E-8 to 1.05E-4).

Table 3-7. CCF data with curve-fitted complete CCF events (pump, non-lethal shocks only).

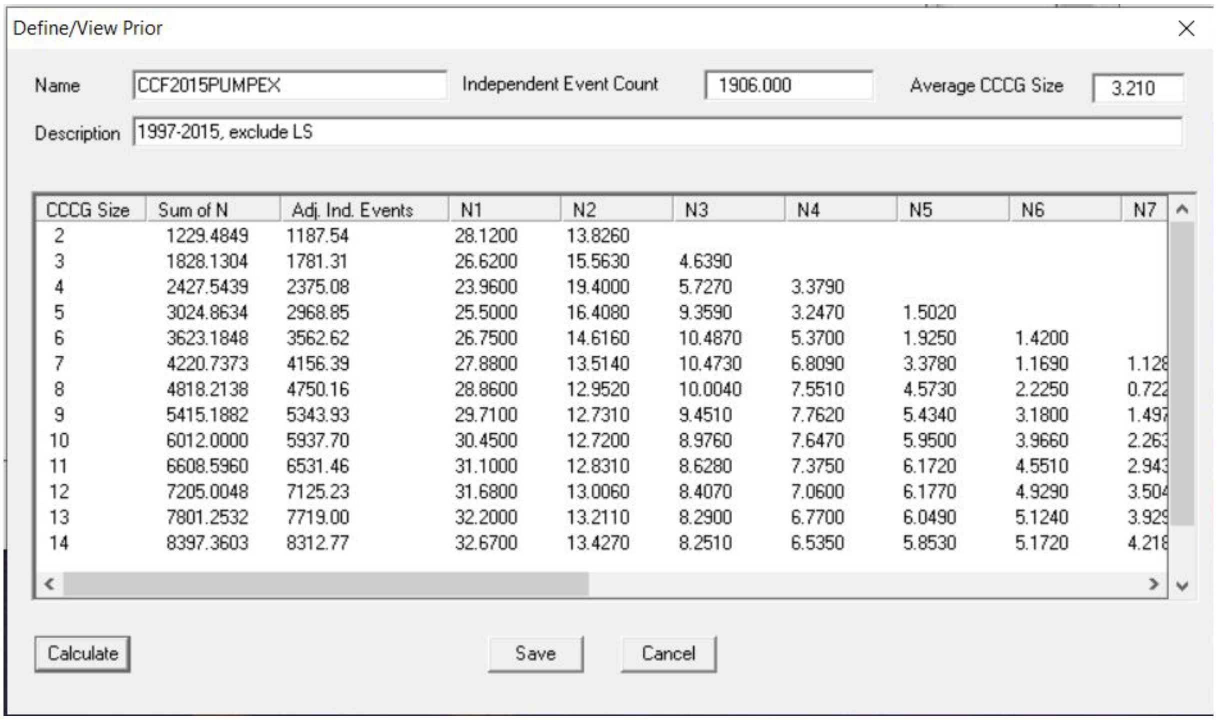
Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events	Prob. of Complete CCF Event - Data	Prob. of Complete CCF Event - Curve Fitting	Estimated No. Complete CCF Events
2	10	6	16	0.375	0.375	5.999
3	10	2	12	0.167	0.167	2.000
4	14	0	14	0.000	0.118	1.649
5	1	0	1	0.000	0.103	0.103
6	2	0	2	0.000	0.098	0.196
7	0	0	0	NA	0.096	0.000
8	1	0	1	0.000	0.096	0.096
9	0	0	0	NA	0.096	0.000
10	0	0	0	NA	0.095	0.000
11	0	0	0	NA	0.095	0.000
12	0	0	0	NA	0.095	0.000
13	0	0	0	NA	0.095	0.000
14	0	0	0	NA	0.095	0.000
15	0	0	0	NA	0.095	0.000
16	0	0	0	NA	0.095	0.000
Total	38	8	46	—	—	10.043

Table 3-8. Adjusted n_k values for CCF events (pump, distinguishing lethal shocks from non-lethal shocks).

Group Size	n_t	n_I	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	1228.47	1186.52	28.12	13.826	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	1826.59	1779.77	26.62	15.563	4.639	—	—	—	—	—	—	—	—	—	—	—	—	—
4	2425.50	2373.03	23.96	19.400	5.727	3.379	—	—	—	—	—	—	—	—	—	—	—	—
5	3022.31	2966.29	25.50	16.408	9.359	3.247	1.502	—	—	—	—	—	—	—	—	—	—	—
6	3620.12	3559.55	26.75	14.616	10.487	5.370	1.925	1.420	—	—	—	—	—	—	—	—	—	—
7	4217.16	4152.81	27.88	13.514	10.473	6.809	3.378	1.169	1.128	—	—	—	—	—	—	—	—	—
8	4814.13	4746.07	28.86	12.952	10.004	7.551	4.573	2.225	0.722	1.171	—	—	—	—	—	—	—	—
9	5410.58	5339.32	29.71	12.731	9.451	7.762	5.434	3.180	1.497	0.453	1.045	—	—	—	—	—	—	—
10	6006.89	5932.58	30.45	12.720	8.976	7.647	5.950	3.966	2.263	1.019	0.287	1.0273	—	—	—	—	—	—
11	6602.97	6525.84	31.10	12.831	8.628	7.375	6.172	4.551	2.943	1.631	0.699	0.1849	1.0169	—	—	—	—	—
12	7198.87	7119.10	31.68	13.006	8.407	7.060	6.177	4.929	3.504	2.210	1.184	0.4832	0.1204	1.0106	—	—	—	—
13	7794.61	7712.36	32.20	13.211	8.290	6.770	6.049	5.124	3.929	2.720	1.671	0.8640	0.3361	0.0792	1.0068	—	—	—
14	8390.20	8305.61	32.67	13.427	8.251	6.535	5.853	5.172	4.218	3.143	2.124	1.2693	0.6333	0.2352	0.0526	1.0043	—	—
15	8985.66	8898.87	33.09	13.642	8.263	6.363	5.640	5.118	4.382	3.467	2.523	1.6644	0.9675	0.4662	0.1656	0.0352	1.0028	—
16	9581.01	9492.13	33.48	13.852	8.309	6.250	5.440	5.000	4.443	3.692	2.853	2.0294	1.3070	0.7399	0.3446	0.1171	0.0237	1.0018

Table 3-9. Calculated alpha factor mean values (pump, distinguishing lethal shocks from non-lethal shocks).

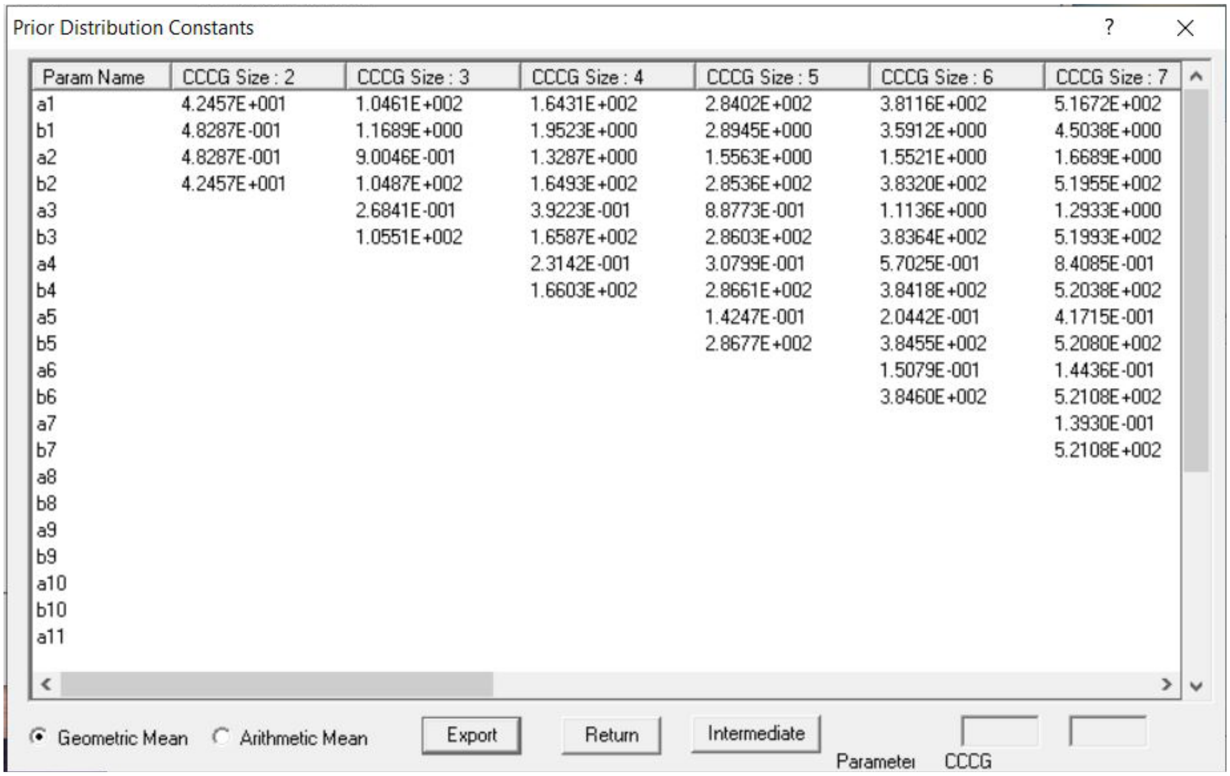
Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9887	1.125E-02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9889	8.520E-03	2.540E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9882	7.998E-03	2.361E-03	1.393E-03	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9899	5.429E-03	3.097E-03	1.074E-03	4.970E-04	—	—	—	—	—	—	—	—	—	—	—
6	0.9907	4.037E-03	2.897E-03	1.483E-03	5.318E-04	3.923E-04	—	—	—	—	—	—	—	—	—	—
7	0.9914	3.205E-03	2.483E-03	1.615E-03	8.010E-04	2.772E-04	2.675E-04	—	—	—	—	—	—	—	—	—
8	0.9919	2.690E-03	2.078E-03	1.569E-03	9.499E-04	4.622E-04	1.500E-04	2.432E-04	—	—	—	—	—	—	—	—
9	0.9923	2.353E-03	1.747E-03	1.435E-03	1.004E-03	5.877E-04	2.767E-04	8.372E-05	1.931E-04	—	—	—	—	—	—	—
10	0.9927	2.118E-03	1.494E-03	1.273E-03	9.905E-04	6.602E-04	3.767E-04	1.696E-04	4.778E-05	1.710E-04	—	—	—	—	—	—
11	0.9930	1.943E-03	1.307E-03	1.117E-03	9.347E-04	6.892E-04	4.457E-04	2.470E-04	1.059E-04	2.800E-05	1.540E-04	—	—	—	—	—
12	0.9933	1.807E-03	1.168E-03	9.807E-04	8.581E-04	6.847E-04	4.867E-04	3.070E-04	1.645E-04	6.712E-05	1.672E-05	1.404E-04	—	—	—	—
13	0.9936	1.695E-03	1.064E-03	8.685E-04	7.760E-04	6.574E-04	5.041E-04	3.490E-04	2.144E-04	1.108E-04	4.312E-05	1.016E-05	1.292E-04	—	—	—
14	0.9938	1.600E-03	9.834E-04	7.789E-04	6.976E-04	6.164E-04	5.027E-04	3.746E-04	2.532E-04	1.513E-04	7.548E-05	2.803E-05	6.269E-06	1.197E-04	—	—
15	0.9940	1.518E-03	9.196E-04	7.081E-04	6.277E-04	5.696E-04	4.877E-04	3.858E-04	2.808E-04	1.852E-04	1.077E-04	5.188E-05	1.843E-05	3.917E-06	1.116E-04	—
16	0.9942	1.446E-03	8.672E-04	6.523E-04	5.678E-04	5.219E-04	4.637E-04	3.853E-04	2.978E-04	2.118E-04	1.364E-04	7.723E-05	3.597E-05	1.222E-05	2.474E-06	1.046E-04



Name: CCF2015PUMPEX
Independent Event Count: 1906.000
Average CCCG Size: 3.210
Description: 1997-2015, exclude LS

CCCG Size	Sum of N	Adj. Ind. Events	N1	N2	N3	N4	N5	N6	N7
2	1229.4849	1187.54	28.1200	13.8260					
3	1828.1304	1781.31	26.6200	15.5630	4.6390				
4	2427.5439	2375.08	23.9600	19.4000	5.7270	3.3790			
5	3024.8634	2968.85	25.5000	16.4080	9.3590	3.2470	1.5020		
6	3623.1848	3562.62	26.7500	14.6160	10.4870	5.3700	1.9250	1.4200	
7	4220.7373	4156.39	27.8800	13.5140	10.4730	6.8090	3.3780	1.1690	1.128
8	4818.2138	4750.16	28.8600	12.9520	10.0040	7.5510	4.5730	2.2250	0.722
9	5415.1882	5343.93	29.7100	12.7310	9.4510	7.7620	5.4340	3.1800	1.497
10	6012.0000	5937.70	30.4500	12.7200	8.9760	7.6470	5.9500	3.9660	2.263
11	6608.5960	6531.46	31.1000	12.8310	8.6280	7.3750	6.1720	4.5510	2.943
12	7205.0048	7125.23	31.6800	13.0060	8.4070	7.0600	6.1770	4.9290	3.504
13	7801.2532	7719.00	32.2000	13.2110	8.2900	6.7700	6.0490	5.1240	3.929
14	8397.3603	8312.77	32.6700	13.4270	8.2510	6.5350	5.8530	5.1720	4.218

Figure 3-3. Input to the CalcPrior code for estimating CCF prior distributions (pump, distinguishing lethal shocks from non-lethal shocks).



Param Name	CCCG Size : 2	CCCG Size : 3	CCCG Size : 4	CCCG Size : 5	CCCG Size : 6	CCCG Size : 7
a1	4.2457E+001	1.0461E+002	1.6431E+002	2.8402E+002	3.8116E+002	5.1672E+002
b1	4.8287E-001	1.1689E+000	1.9523E+000	2.8945E+000	3.5912E+000	4.5038E+000
a2	4.8287E-001	9.0046E-001	1.3287E+000	1.5563E+000	1.5521E+000	1.6689E+000
b2	4.2457E+001	1.0487E+002	1.6493E+002	2.8536E+002	3.8320E+002	5.1955E+002
a3		2.6841E-001	3.9223E-001	8.8773E-001	1.1136E+000	1.2933E+000
b3		1.0551E+002	1.6587E+002	2.8603E+002	3.8364E+002	5.1993E+002
a4			2.3142E-001	3.0799E-001	5.7025E-001	8.4085E-001
b4			1.6603E+002	2.8661E+002	3.8418E+002	5.2038E+002
a5				1.4247E-001	2.0442E-001	4.1715E-001
b5				2.8677E+002	3.8455E+002	5.2080E+002
a6					1.5079E-001	1.4436E-001
b6					3.8460E+002	5.2108E+002
a7						1.3930E-001
b7						5.2108E+002
a8						
b8						
a9						
b9						
a10						
b10						
a11						

● Geometric Mean ○ Arithmetic Mean

Figure 3-4. CCF prior distribution parameters calculated by the CalcPrior code (pump, distinguishing lethal shocks from non-lethal shocks).

Table 3-10. Estimated industry-wide alpha factor prior distributions (pump, distinguishing lethal shocks from non-lethal shocks).

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	4.25E+01	4.83E-01	4.83E-01	4.25E+01	—	—	—	—	—	—	—	—	—	—	—	—
3	1.05E+02	1.17E+00	9.00E-01	1.05E+02	2.68E-01	1.06E+02	—	—	—	—	—	—	—	—	—	—
4	1.64E+02	1.95E+00	1.33E+00	1.65E+02	3.92E-01	1.66E+02	2.31E-01	1.66E+02	—	—	—	—	—	—	—	—
5	2.84E+02	2.89E+00	1.56E+00	2.85E+02	8.88E-01	2.86E+02	3.08E-01	2.87E+02	1.42E-01	2.87E+02	—	—	—	—	—	—
6	3.81E+02	3.59E+00	1.55E+00	3.83E+02	1.11E+00	3.84E+02	5.70E-01	3.84E+02	2.04E-01	3.85E+02	1.51E-01	3.85E+02	—	—	—	—
7	5.17E+02	4.50E+00	1.67E+00	5.20E+02	1.29E+00	5.20E+02	8.41E-01	5.20E+02	4.17E-01	5.21E+02	1.44E-01	5.21E+02	1.39E-01	5.21E+02	—	—
8	6.55E+02	5.37E+00	1.77E+00	6.58E+02	1.37E+00	6.59E+02	1.03E+00	6.59E+02	6.27E-01	6.59E+02	3.05E-01	6.60E+02	9.89E-02	6.60E+02	1.60E-01	6.60E+02
9	8.33E+02	6.44E+00	1.97E+00	8.38E+02	1.47E+00	8.38E+02	1.20E+00	8.38E+02	8.42E-01	8.39E+02	4.93E-01	8.39E+02	2.32E-01	8.39E+02	7.02E-02	8.39E+02
10	1.03E+03	7.57E+00	2.20E+00	1.04E+03	1.55E+00	1.04E+03	1.32E+00	1.04E+03	1.03E+00	1.04E+03	6.85E-01	1.04E+03	3.91E-01	1.04E+03	1.76E-01	1.04E+03
11	1.26E+03	8.81E+00	2.46E+00	1.26E+03	1.65E+00	1.26E+03	1.41E+00	1.26E+03	1.18E+00	1.26E+03	8.71E-01	1.26E+03	5.63E-01	1.26E+03	3.12E-01	1.26E+03
12	1.51E+03	1.02E+01	2.75E+00	1.52E+03	1.78E+00	1.52E+03	1.49E+00	1.52E+03	1.31E+00	1.52E+03	1.04E+00	1.52E+03	7.41E-01	1.52E+03	4.67E-01	1.52E+03
13	1.80E+03	1.16E+01	3.07E+00	1.81E+03	1.93E+00	1.81E+03	1.58E+00	1.81E+03	1.41E+00	1.81E+03	1.19E+00	1.81E+03	9.14E-01	1.81E+03	6.33E-01	1.81E+03
14	2.13E+03	1.32E+01	3.43E+00	2.14E+03	2.11E+00	2.14E+03	1.67E+00	2.14E+03	1.49E+00	2.14E+03	1.32E+00	2.14E+03	1.08E+00	2.14E+03	8.02E-01	2.14E+03
15	2.49E+03	1.50E+01	3.80E+00	2.50E+03	2.30E+00	2.50E+03	1.77E+00	2.50E+03	1.57E+00	2.50E+03	1.45E+00	2.50E+03	1.22E+00	2.50E+03	9.66E-01	2.50E+03
16	2.90E+03	1.68E+01	4.21E+00	2.91E+03	2.53E+00	2.91E+03	1.90E+00	2.91E+03	1.65E+00	2.91E+03	1.52E+00	2.91E+03	1.35E+00	2.91E+03	1.12E+00	2.91E+03

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	1.62E-01	8.39E+02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	4.96E-02	1.04E+03	1.77E-01	1.04E+03	—	—	—	—	—	—	—	—	—	—	—	—
11	1.34E-01	1.27E+03	3.54E-02	1.27E+03	1.95E-01	1.26E+03	—	—	—	—	—	—	—	—	—	—
12	2.50E-01	1.52E+03	1.02E-01	1.52E+03	2.55E-02	1.52E+03	2.14E-01	1.52E+03	—	—	—	—	—	—	—	—
13	3.89E-01	1.81E+03	2.01E-01	1.82E+03	7.82E-02	1.82E+03	1.84E-02	1.82E+03	2.34E-01	1.82E+03	—	—	—	—	—	—
14	5.42E-01	2.14E+03	3.24E-01	2.14E+03	1.62E-01	2.14E+03	6.00E-02	2.14E+03	1.34E-02	2.14E+03	2.56E-01	2.14E+03	—	—	—	—
15	7.03E-01	2.51E+03	4.64E-01	2.51E+03	2.70E-01	2.51E+03	1.30E-01	2.51E+03	4.61E-02	2.51E+03	9.81E-03	2.51E+03	2.79E-01	2.51E+03	—	—
16	8.67E-01	2.91E+03	6.17E-01	2.91E+03	3.97E-01	2.91E+03	2.25E-01	2.91E+03	1.05E-01	2.91E+03	3.56E-02	2.91E+03	7.20E-03	2.91E+03	3.04E-01	2.91E+03

4. DEVELOPING PRIOR DISTRIBUTIONS OF ALPHA FACTORS SPECIFIC TO VALVE COMPONENTS

This section presents the development of the prior distributions of alpha factors specific to valve components.

4.1 Accessing CCF Data

To estimate the prior distributions for the valve component type, the following selection criteria are defined on the NRC RADS CCF database website.

- Type of CCF Event Level: All Level CCF Events
- CCF Event Type: CCF Events Only
- Date Range: 1997–2015
- Filter Independent Events by Selected Cause(s): True
- Shock Criteria: All Events
- Redundancy Range: Minimum = 2, Maximum = 16
- Bayesian Update Method: Mean Method
- Failure Modes: select all failure modes except Setpoint
- CCF Categories: Components → Valve

A total of 123 CCF events and 1,814.3 effective independent failure events related to the above selection criteria. Table 4-1 shows the number of partial CCF events, the number of complete CCF events, and the total number of CCF events. Table 4-2 shows the mapped impact vectors for partial CCF events pertaining to each group size (2–16), as obtained from the CCF database website.

Table 4-1. CCF data (valve).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events
2	9	11	20
3	12	5	17
4	28	2	30
5	3	0	3
6	10	0	10
7	2	0	2
8	28	1	29
9	0	0	0
10	0	0	0
11	5	0	5
12	2	0	2
13	0	0	0
14	1	0	1
15	0	0	0
16	4	0	4
Total	104	19	123

Table 4-2. n_k values for partial CCF events (valve).

Group Size	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	51.05	15.332	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	46.42	30.656	4.780	—	—	—	—	—	—	—	—	—	—	—	—	—
4	40.96	35.379	13.563	2.195	—	—	—	—	—	—	—	—	—	—	—	—
5	39.77	32.829	18.309	7.940	1.206	—	—	—	—	—	—	—	—	—	—	—
6	39.27	29.829	20.516	11.454	4.849	0.685	—	—	—	—	—	—	—	—	—	—
7	39.50	28.157	19.025	14.147	8.099	2.901	0.417	—	—	—	—	—	—	—	—	—
8	39.11	27.874	17.669	14.116	10.844	5.508	1.728	0.279	—	—	—	—	—	—	—	—
9	38.65	27.885	16.725	13.959	11.285	7.672	3.903	1.153	0.194	—	—	—	—	—	—	—
10	37.96	28.007	16.349	13.321	11.466	8.766	5.639	2.778	0.789	0.140	—	—	—	—	—	—
11	37.11	28.164	16.368	12.621	11.288	9.356	6.809	4.231	1.984	0.557	0.104	—	—	—	—	—
12	36.53	28.081	16.290	12.279	10.805	9.654	7.530	5.355	3.203	1.424	0.407	0.0794	—	—	—	—
13	36.07	27.765	16.374	12.149	10.204	9.613	8.100	6.016	4.306	2.406	1.037	0.3072	0.0613	—	—	—
14	35.54	27.548	16.416	12.164	9.853	8.935	8.828	6.316	5.056	3.447	1.788	0.7747	0.2385	0.0477	—	—
15	34.93	27.441	16.367	12.312	9.568	8.669	8.391	7.157	5.231	4.383	2.672	1.3322	0.5997	0.1882	0.0374	—
16	34.24	27.461	16.191	12.572	9.364	8.385	8.025	7.379	5.914	4.318	3.978	1.8818	1.0544	0.4718	0.1503	0.0294

4.2 Treating Complete CCF Events

This section presents the curve-fitting results for the fraction of complete CCF events over the total number of CCF events for the valve components. The results (i.e., the probability of a complete CCF event and the estimated number of complete CCF events for each group size) are listed in the last two columns of Table 4-3.

A review of the valve CCF data revealed two CCF events coded as lethal shock events, both corresponding to a group size of 2. Sensitivity studies were conducted to examine the impacts of distinguishing lethal shocks from non-lethal-shock-but-complete-CCF events. The sensitivity analysis results are presented in Section 4.4.

Table 4-3. CCF data with curve-fitted complete CCF events (valve).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events	Prob. of Complete CCF Event - Data	Prob. of Complete CCF Event - Curve Fitting	Estimated No. Complete CCF Events
2	9	11	20	0.550	0.618	12.350
3	12	5	17	0.294	0.156	2.650
4	28	2	30	0.067	0.077	2.300
5	3	0	3	0.000	0.058	0.170
6	10	0	10	0.000	0.053	0.530
7	2	0	2	0.000	0.051	0.100
8	28	1	29	0.034	0.050	1.450

Table 4-3. (continued).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events	Prob. of Complete CCF Event - Data	Prob. of Complete CCF Event - Curve Fitting	Estimated No. Complete CCF Events
9	0	0	0	NA	0.050	0.000
10	0	0	0	NA	0.050	0.000
11	5	0	5	0.000	0.050	0.250
12	2	0	2	0.000	0.050	0.100
13	0	0	0	NA	0.050	0.000
14	1	0	1	0.000	0.050	0.050
15	0	0	0	NA	0.050	0.000
16	4	0	4	0.000	0.050	0.200
Total	104	19	123	—	—	20.150

4.3 Estimating Prior Distributions

Adjusted n_k values for valve CCF events were obtained for each group size by adding the estimated number of complete CCF events to the final n_k value for the partial CCF events. Table 4-4 shows the adjusted n_k results, as well as the n_I and n_t results, of the valve CCF data for group sizes 2–16. The calculated MLEs (i.e., alpha factor mean values) for each group size are given in Table 4-5.

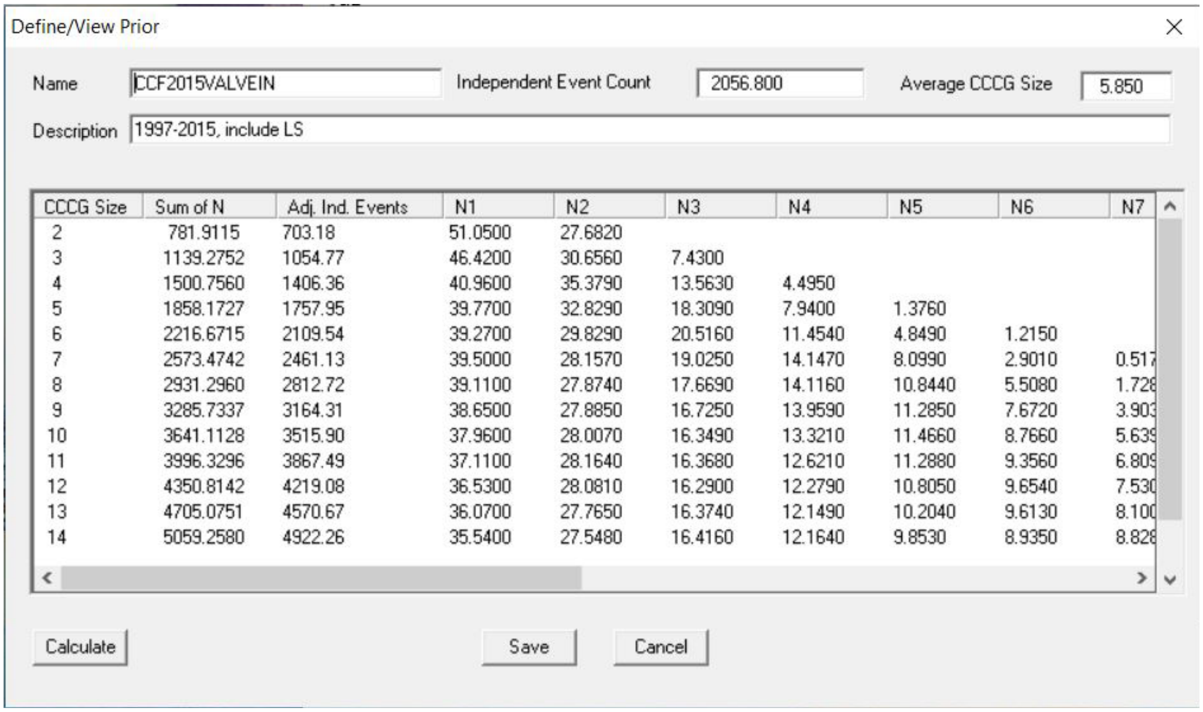
Adjusted n_k and n_I values were input to the computer code CalcPrior to estimate the industry-wide prior distributions with parameters α and β. Figure 4-1 shows the code's needed input for calculating the prior distributions. Figure 4-2 shows the CalcPrior results for the prior distribution parameters, which were then output to Table 4-6. .

Table 4-4. Adjusted n_k values for all CCF events (valve).

Group Size	n_t	n_I	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	782.01	703.27	51.05	27.682	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	1139.42	1054.91	46.42	30.656	7.430	—	—	—	—	—	—	—	—	—	—	—	—	—
4	1500.95	1406.55	40.96	35.379	13.563	4.495	—	—	—	—	—	—	—	—	—	—	—	—
5	1858.41	1758.19	39.77	32.829	18.309	7.940	1.376	—	—	—	—	—	—	—	—	—	—	—
6	2216.95	2109.82	39.27	29.829	20.516	11.454	4.849	1.215	—	—	—	—	—	—	—	—	—	—
7	2573.80	2461.46	39.50	28.157	19.025	14.147	8.099	2.901	0.517	—	—	—	—	—	—	—	—	—
8	2931.68	2813.10	39.11	27.874	17.669	14.116	10.844	5.508	1.728	1.729	—	—	—	—	—	—	—	—
9	3286.16	3164.74	38.65	27.885	16.725	13.959	11.285	7.672	3.903	1.153	0.194	—	—	—	—	—	—	—
10	3641.59	3516.37	37.96	28.007	16.349	13.321	11.466	8.766	5.639	2.778	0.789	0.1404	—	—	—	—	—	—
11	3996.85	3868.01	37.11	28.164	16.368	12.621	11.288	9.356	6.809	4.231	1.984	0.5569	0.3545	—	—	—	—	—
12	4351.39	4219.65	36.53	28.081	16.290	12.279	10.805	9.654	7.530	5.355	3.203	1.4243	0.4066	0.1794	—	—	—	—
13	4705.70	4571.29	36.07	27.765	16.374	12.149	10.204	9.613	8.100	6.016	4.306	2.4064	1.0365	0.3072	0.0613	—	—	—
14	5059.92	4922.92	35.54	27.548	16.416	12.164	9.853	8.935	8.828	6.316	5.056	3.4465	1.7882	0.7747	0.2385	0.0977	—	—
15	5413.84	5274.56	34.93	27.441	16.367	12.312	9.568	8.669	8.391	7.157	5.231	4.3834	2.6723	1.3322	0.5997	0.1882	0.0374	—
16	5767.82	5626.20	34.24	27.461	16.191	12.572	9.364	8.385	8.025	7.379	5.914	4.3178	3.9780	1.8818	1.0544	0.4718	0.1503	0.2294

Table 4-5. Calculated alpha factor mean values (valve).

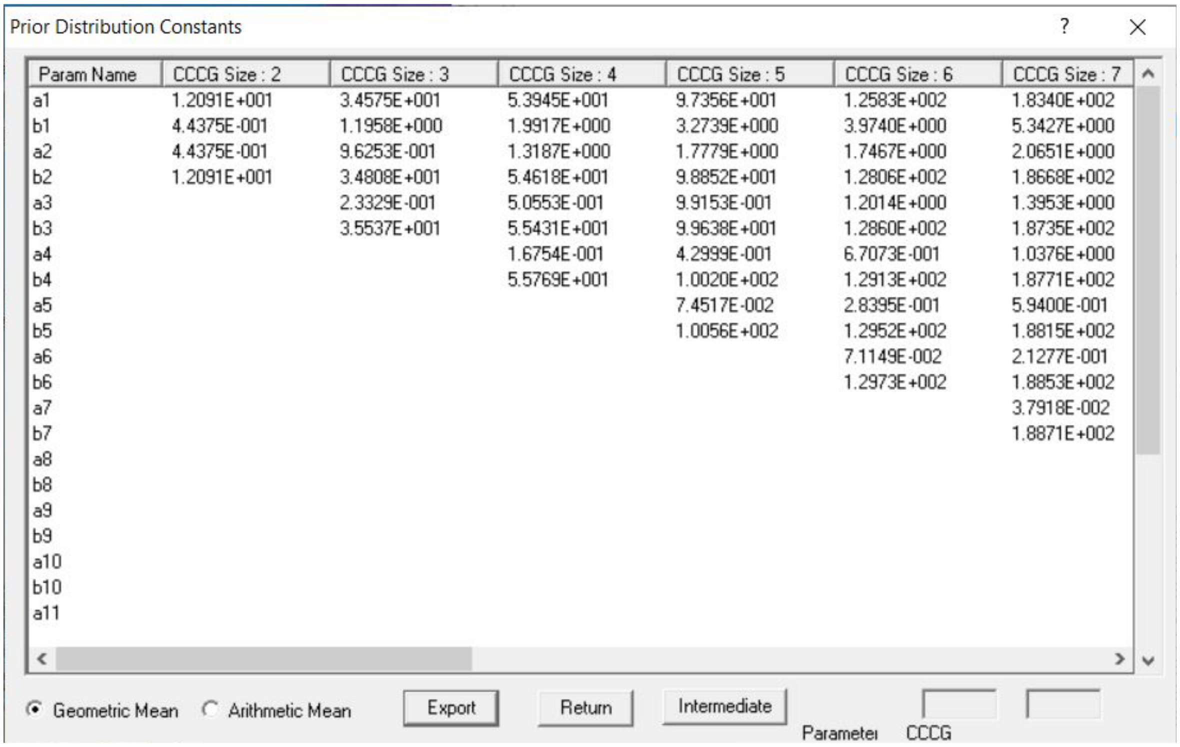
Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9646	3.540E-02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9666	2.690E-02	6.521E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9644	2.357E-02	9.036E-03	2.995E-03	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9675	1.767E-02	9.852E-03	4.272E-03	7.401E-04	—	—	—	—	—	—	—	—	—	—	—
6	0.9694	1.345E-02	9.254E-03	5.167E-03	2.187E-03	5.480E-04	—	—	—	—	—	—	—	—	—	—
7	0.9717	1.094E-02	7.392E-03	5.497E-03	3.147E-03	1.127E-03	2.009E-04	—	—	—	—	—	—	—	—	—
8	0.9729	9.508E-03	6.027E-03	4.815E-03	3.699E-03	1.879E-03	5.895E-04	5.898E-04	—	—	—	—	—	—	—	—
9	0.9748	8.486E-03	5.090E-03	4.248E-03	3.434E-03	2.335E-03	1.188E-03	3.508E-04	5.917E-05	—	—	—	—	—	—	—
10	0.9760	7.691E-03	4.490E-03	3.658E-03	3.149E-03	2.407E-03	1.548E-03	7.628E-04	2.168E-04	3.855E-05	—	—	—	—	—	—
11	0.9770	7.047E-03	4.095E-03	3.158E-03	2.824E-03	2.341E-03	1.704E-03	1.059E-03	4.964E-04	1.393E-04	8.868E-05	—	—	—	—	—
12	0.9781	6.453E-03	3.744E-03	2.822E-03	2.483E-03	2.219E-03	1.730E-03	1.231E-03	7.360E-04	3.273E-04	9.344E-05	4.124E-05	—	—	—	—
13	0.9791	5.900E-03	3.480E-03	2.582E-03	2.168E-03	2.043E-03	1.721E-03	1.278E-03	9.150E-04	5.114E-04	2.203E-04	6.528E-05	1.303E-05	—	—	—
14	0.9799	5.444E-03	3.244E-03	2.404E-03	1.947E-03	1.766E-03	1.745E-03	1.248E-03	9.992E-04	6.811E-04	3.534E-04	1.531E-04	4.713E-05	1.931E-05	—	—
15	0.9807	5.069E-03	3.023E-03	2.274E-03	1.767E-03	1.601E-03	1.550E-03	1.322E-03	9.663E-04	8.097E-04	4.936E-04	2.461E-04	1.108E-04	3.476E-05	6.906E-06	—
16	0.9814	4.761E-03	2.807E-03	2.180E-03	1.623E-03	1.454E-03	1.391E-03	1.279E-03	1.025E-03	7.486E-04	6.897E-04	3.263E-04	1.828E-04	8.180E-05	2.606E-05	3.978E-05



Name: CCF2015VALVEIN
Independent Event Count: 2056.800
Average CCCG Size: 5.850
Description: 1997-2015, include LS

CCCG Size	Sum of N	Adj. Ind. Events	N1	N2	N3	N4	N5	N6	N7
2	781.9115	703.18	51.0500	27.6820					
3	1139.2752	1054.77	46.4200	30.6560	7.4300				
4	1500.7560	1406.36	40.9600	35.3790	13.5630	4.4950			
5	1858.1727	1757.95	39.7700	32.8290	18.3090	7.9400	1.3760		
6	2216.6715	2109.54	39.2700	29.8290	20.5160	11.4540	4.8490	1.2150	
7	2573.4742	2461.13	39.5000	28.1570	19.0250	14.1470	8.0990	2.9010	0.51
8	2931.2960	2812.72	39.1100	27.8740	17.6690	14.1160	10.8440	5.5080	1.72
9	3285.7337	3164.31	38.6500	27.8850	16.7250	13.9590	11.2850	7.6720	3.90
10	3641.1128	3515.90	37.9600	28.0070	16.3490	13.3210	11.4660	8.7660	5.63
11	3996.3296	3867.49	37.1100	28.1640	16.3680	12.6210	11.2880	9.3560	6.80
12	4350.8142	4219.08	36.5300	28.0810	16.2900	12.2790	10.8050	9.6540	7.53
13	4705.0751	4570.67	36.0700	27.7650	16.3740	12.1490	10.2040	9.6130	8.10
14	5059.2580	4922.26	35.5400	27.5480	16.4160	12.1640	9.8530	8.9350	8.82

Figure 4-1. Input to the CalcPrior code for estimating CCF prior distributions (valve).



Param Name	CCCG Size : 2	CCCG Size : 3	CCCG Size : 4	CCCG Size : 5	CCCG Size : 6	CCCG Size : 7
a1	1.2091E+001	3.4575E+001	5.3945E+001	9.7356E+001	1.2583E+002	1.8340E+002
b1	4.4375E-001	1.1958E+000	1.9917E+000	3.2739E+000	3.9740E+000	5.3427E+000
a2	4.4375E-001	9.6253E-001	1.3187E+000	1.7779E+000	1.7467E+000	2.0651E+000
b2	1.2091E+001	3.4808E+001	5.4618E+001	9.8852E+001	1.2806E+002	1.8668E+002
a3		2.3329E-001	5.0553E-001	9.9153E-001	1.2014E+000	1.3953E+000
b3		3.5537E+001	5.5431E+001	9.9638E+001	1.2860E+002	1.8735E+002
a4			1.6754E-001	4.2999E-001	6.7073E-001	1.0376E+000
b4			5.5769E+001	1.0020E+002	1.2913E+002	1.8771E+002
a5				7.4517E-002	2.8395E-001	5.9400E-001
b5				1.0056E+002	1.2952E+002	1.8815E+002
a6					7.1149E-002	2.1277E-001
b6					1.2973E+002	1.8853E+002
a7						3.7918E-002
b7						1.8871E+002
a8						
b8						
a9						
b9						
a10						
b10						
a11						

● Geometric Mean ○ Arithmetic Mean

Figure 4-2. CCF prior distribution parameters calculated by the CalcPrior code (valve).

Table 4-6. Estimated industry-wide alpha factor prior distributions (valve).

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	1.21E+01	4.44E-01	4.44E-01	1.21E+01	—	—	—	—	—	—	—	—	—	—	—	—
3	3.46E+01	1.20E+00	9.63E-01	3.48E+01	2.33E-01	3.55E+01	—	—	—	—	—	—	—	—	—	—
4	5.39E+01	1.99E+00	1.32E+00	5.46E+01	5.06E-01	5.54E+01	1.68E-01	5.58E+01	—	—	—	—	—	—	—	—
5	9.74E+01	3.27E+00	1.78E+00	9.89E+01	9.92E-01	9.96E+01	4.30E-01	1.00E+02	7.45E-02	1.01E+02	—	—	—	—	—	—
6	1.26E+02	3.97E+00	1.75E+00	1.28E+02	1.20E+00	1.29E+02	6.71E-01	1.29E+02	2.84E-01	1.30E+02	7.11E-02	1.30E+02	—	—	—	—
7	1.83E+02	5.34E+00	2.07E+00	1.87E+02	1.40E+00	1.87E+02	1.04E+00	1.88E+02	5.94E-01	1.88E+02	2.13E-01	1.89E+02	3.79E-02	1.89E+02	—	—
8	1.90E+02	5.29E+00	1.86E+00	1.93E+02	1.18E+00	1.94E+02	9.40E-01	1.94E+02	7.22E-01	1.94E+02	3.67E-01	1.95E+02	1.15E-01	1.95E+02	1.15E-01	1.95E+02
9	3.08E+02	7.97E+00	2.68E+00	3.14E+02	1.61E+00	3.15E+02	1.34E+00	3.15E+02	1.09E+00	3.15E+02	7.38E-01	3.15E+02	3.76E-01	3.16E+02	1.11E-01	3.16E+02
10	3.77E+02	9.26E+00	2.97E+00	3.83E+02	1.74E+00	3.85E+02	1.41E+00	3.85E+02	1.22E+00	3.85E+02	9.30E-01	3.85E+02	5.98E-01	3.86E+02	2.95E-01	3.86E+02
11	4.01E+02	9.43E+00	2.89E+00	4.08E+02	1.68E+00	4.09E+02	1.30E+00	4.09E+02	1.16E+00	4.10E+02	9.62E-01	4.10E+02	7.00E-01	4.10E+02	4.35E-01	4.10E+02
12	4.99E+02	1.12E+01	3.30E+00	5.07E+02	1.91E+00	5.09E+02	1.44E+00	5.09E+02	1.27E+00	5.09E+02	1.13E+00	5.09E+02	8.84E-01	5.10E+02	6.28E-01	5.10E+02
13	6.30E+02	1.35E+01	3.80E+00	6.40E+02	2.24E+00	6.41E+02	1.66E+00	6.42E+02	1.40E+00	6.42E+02	1.32E+00	6.42E+02	1.11E+00	6.43E+02	8.23E-01	6.43E+02
14	6.92E+02	1.42E+01	3.84E+00	7.02E+02	2.29E+00	7.03E+02	1.70E+00	7.04E+02	1.37E+00	7.04E+02	1.25E+00	7.04E+02	1.23E+00	7.04E+02	8.81E-01	7.05E+02
15	8.39E+02	1.65E+01	4.34E+00	8.51E+02	2.59E+00	8.53E+02	1.95E+00	8.54E+02	1.51E+00	8.54E+02	1.37E+00	8.54E+02	1.33E+00	8.54E+02	1.13E+00	8.54E+02
16	8.35E+02	1.58E+01	4.05E+00	8.46E+02	2.39E+00	8.48E+02	1.85E+00	8.49E+02	1.38E+00	8.49E+02	1.24E+00	8.49E+02	1.18E+00	8.49E+02	1.09E+00	8.49E+02

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	1.87E-02	3.16E+02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	8.37E-02	3.86E+02	1.49E-02	3.86E+02	—	—	—	—	—	—	—	—	—	—	—	—
11	2.04E-01	4.10E+02	5.72E-02	4.11E+02	3.64E-02	4.11E+02	—	—	—	—	—	—	—	—	—	—
12	3.76E-01	5.10E+02	1.67E-01	5.10E+02	4.77E-02	5.11E+02	2.11E-02	5.11E+02	—	—	—	—	—	—	—	—
13	5.89E-01	6.43E+02	3.29E-01	6.43E+02	1.42E-01	6.43E+02	4.20E-02	6.44E+02	8.39E-03	6.44E+02	—	—	—	—	—	—
14	7.05E-01	7.05E+02	4.81E-01	7.05E+02	2.49E-01	7.05E+02	1.08E-01	7.06E+02	3.33E-02	7.06E+02	1.36E-02	7.06E+02	—	—	—	—
15	8.27E-01	8.55E+02	6.93E-01	8.55E+02	4.22E-01	8.55E+02	2.11E-01	8.55E+02	9.48E-02	8.55E+02	2.97E-02	8.56E+02	5.91E-03	8.56E+02	—	—
16	8.72E-01	8.49E+02	6.37E-01	8.50E+02	5.87E-01	8.50E+02	2.77E-01	8.50E+02	1.55E-01	8.50E+02	6.96E-02	8.50E+02	2.22E-02	8.50E+02	3.38E-02	8.50E+02

4.4 Sensitivity Study

This section presents the sensitivity study results for valve components when distinguishing the **two valve lethal shock events** from the non-lethal-shock-but-complete-CCF events in Table 4-7 and adding the number of lethal shock events to the final n_k values of the corresponding group size in Table 4-8. Thus, in Table 4-7, for the group size of two, the number of complete CCF events with non-lethal shocks is nine instead of 11, as there are two lethal shock events. These two lethal shock events are added to the n_m (for the group size of m) values in Table 4-2, along with the new estimated number of complete CCF events (with non-lethal shocks only) in Table 4-3. Now, in Table 4-8, the adjusted n_3 for the group size of 3 is 9.320 instead of 7.430, and the adjusted n_{16} for the group size of 16 is 2.2294 instead of 0.2294, which is the value given in Table 4-4.

Figure 4-3 and Figure 4-4 show the input to and output from the CalcPrior code, respectively. Table 4-9 presents the alpha factor mean values, and Table 4-10 provides the prior distribution parameters for the sensitivity study.

In comparing the values in Table 4-9 to those in Table 4-5, the estimated alpha factor mean values for α_m in the group size of m would be increased when distinguishing lethal shocks from non-lethal shocks in the analysis (e.g., α_3 in the group size of 3 is increased from 6.52E-3 to 8.17E-3, α_4 in the group size of 4 is increased from 3.00E-3 to 4.32E-3, α_8 in the group size of 8 is increased from 5.90E-4 to 1.29E-3, and α_{16} in the group size of 16 is increased from 3.98E-5 to 3.86E-4.

Table 4-7. CCF data with curve-fitted complete CCF events (valve, non-lethal shocks only).

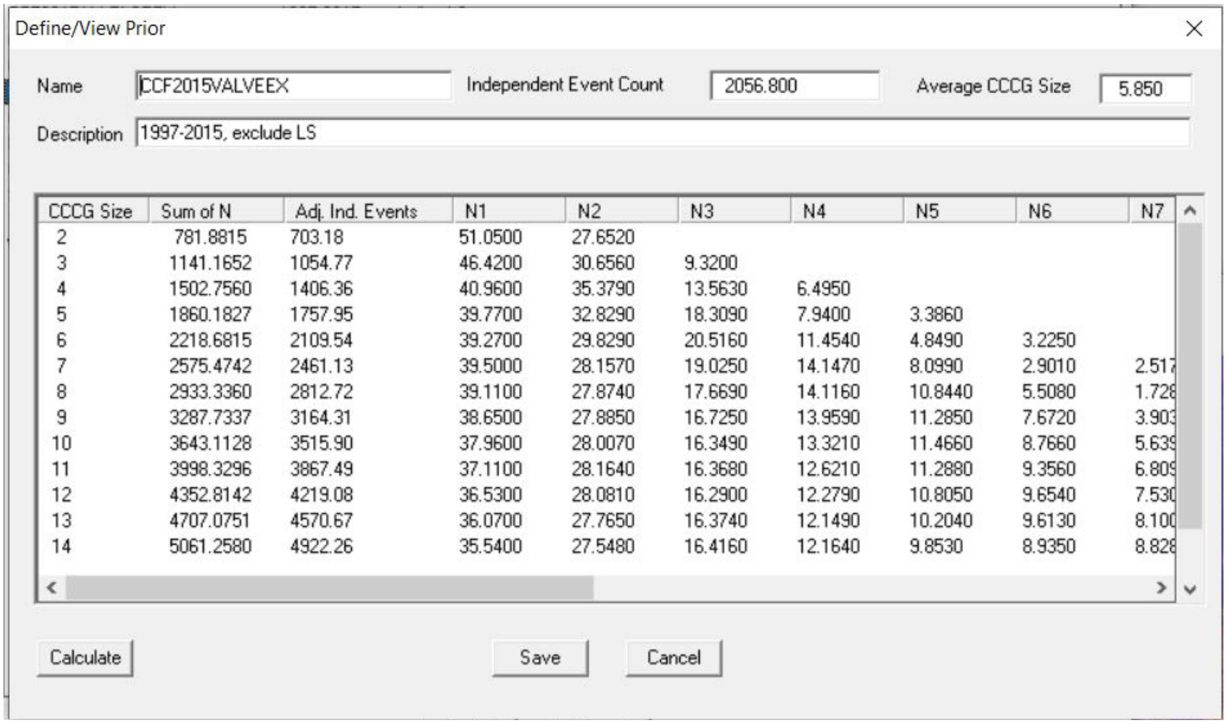
Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events	Prob. of Complete CCF Event - Data	Prob. of Complete CCF Event - Curve Fitting	Estimated No. Complete CCF Events
2	9	9	18	0.500	0.573	10.320
3	12	5	17	0.294	0.149	2.540
4	28	2	30	0.067	0.077	2.300
5	3	0	3	0.000	0.059	0.180
6	10	0	10	0.000	0.054	0.540
7	2	0	2	0.000	0.052	0.100
8	28	1	29	0.034	0.051	1.490
9	0	0	0	NA	0.051	0.000
10	0	0	0	NA	0.051	0.000
11	5	0	5	0.000	0.051	0.250
12	2	0	2	0.000	0.051	0.100
13	0	0	0	NA	0.051	0.000
14	1	0	1	0.000	0.051	0.050
15	0	0	0	NA	0.051	0.000
16	4	0	4	0.000	0.051	0.200
Total	104	17	121	—	—	18.070

Table 4-8. Adjusted *n_k* values for CCF events (valve, distinguishing lethal shocks from non-lethal shocks).

Group Size	n_t	n_I	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	781.98	703.27	51.053	27.652	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	1141.31	1054.91	46.423	30.656	9.320	—	—	—	—	—	—	—	—	—	—	—	—	—
4	1502.95	1406.55	40.962	35.379	13.563	6.495	—	—	—	—	—	—	—	—	—	—	—	—
5	1860.42	1758.19	39.77	32.829	18.309	7.940	3.386	—	—	—	—	—	—	—	—	—	—	—
6	2218.96	2109.82	39.265	29.829	20.516	11.454	4.849	3.225	—	—	—	—	—	—	—	—	—	—
7	2575.80	2461.46	39.495	28.157	19.025	14.147	8.099	2.901	2.517	—	—	—	—	—	—	—	—	—
8	2933.72	2813.10	39.109	27.874	17.669	14.116	10.844	5.508	1.728	3.769	—	—	—	—	—	—	—	—
9	3288.16	3164.74	38.645	27.885	16.725	13.959	11.285	7.672	3.903	1.153	2.194	—	—	—	—	—	—	—
10	3643.59	3516.37	37.964	28.007	16.349	13.321	11.466	8.766	5.639	2.778	0.789	2.1404	—	—	—	—	—	—
11	3998.85	3868.01	37.11	28.164	16.368	12.621	11.288	9.356	6.809	4.231	1.984	0.5569	2.3545	—	—	—	—	—
12	4353.39	4219.65	36.529	28.081	16.290	12.279	10.805	9.654	7.530	5.355	3.203	1.4243	0.4066	2.1794	—	—	—	—
13	4707.70	4571.29	36.071	27.765	16.374	12.149	10.204	9.613	8.100	6.016	4.306	2.4064	1.0365	0.3072	2.0613	—	—	—
14	5061.92	4922.92	35.538	27.548	16.416	12.164	9.853	8.935	8.828	6.316	5.056	3.4465	1.7882	0.7747	0.2385	2.0977	—	—
15	5415.84	5274.56	34.929	27.441	16.367	12.312	9.568	8.669	8.391	7.157	5.231	4.3834	2.6723	1.3322	0.5997	0.1882	2.0374	—
16	5769.82	5626.20	34.244	27.461	16.191	12.572	9.364	8.385	8.025	7.379	5.914	4.3178	3.9780	1.8818	1.0544	0.4718	0.1503	2.2294

Table 4-9. Calculated alpha factor mean values (valve, distinguishing lethal shocks from non-lethal shocks).

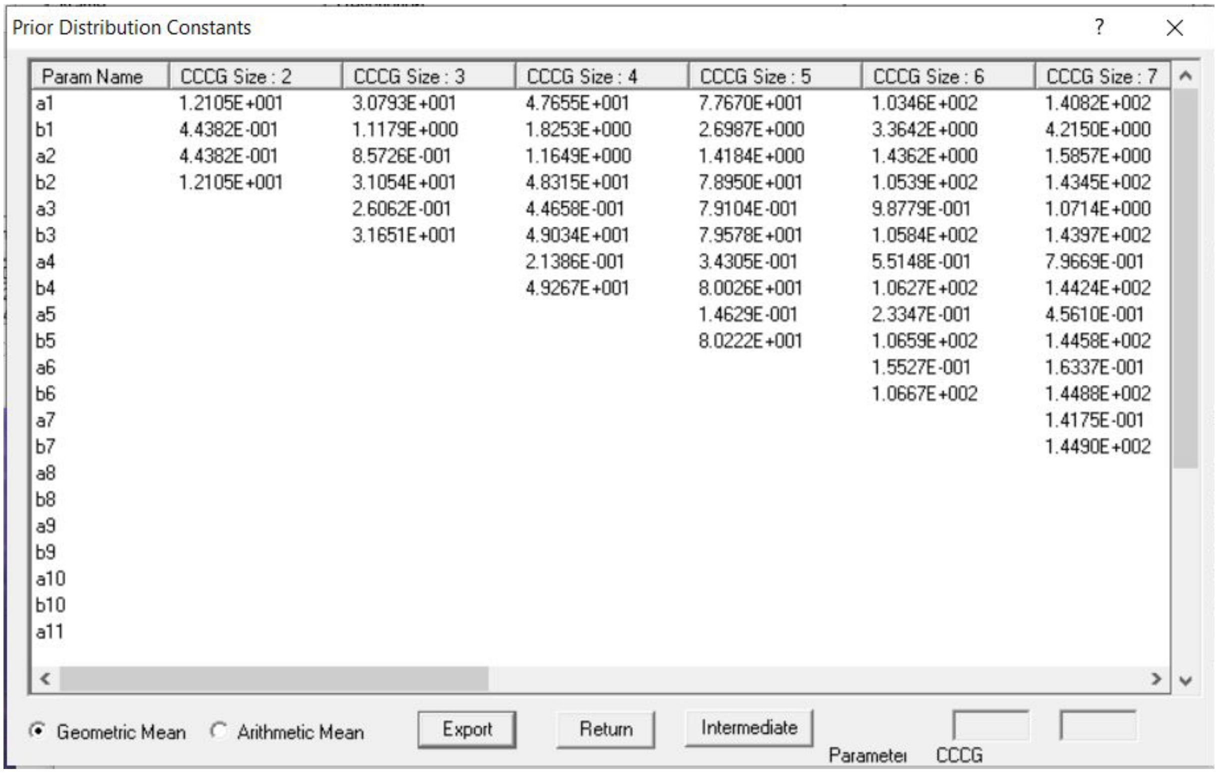
Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9646	3.536E-02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9650	2.686E-02	8.166E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9631	2.354E-02	9.024E-03	4.322E-03	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9664	1.765E-02	9.841E-03	4.268E-03	1.820E-03	—	—	—	—	—	—	—	—	—	—	—
6	0.9685	1.344E-02	9.246E-03	5.162E-03	2.185E-03	1.453E-03	—	—	—	—	—	—	—	—	—	—
7	0.9709	1.093E-02	7.386E-03	5.492E-03	3.144E-03	1.126E-03	9.772E-04	—	—	—	—	—	—	—	—	—
8	0.9722	9.501E-03	6.023E-03	4.812E-03	3.696E-03	1.877E-03	5.890E-04	1.285E-03	—	—	—	—	—	—	—	—
9	0.9742	8.480E-03	5.086E-03	4.245E-03	3.432E-03	2.333E-03	1.187E-03	3.507E-04	6.672E-04	—	—	—	—	—	—	—
10	0.9755	7.687E-03	4.487E-03	3.656E-03	3.147E-03	2.406E-03	1.548E-03	7.624E-04	2.165E-04	5.874E-04	—	—	—	—	—	—
11	0.9766	7.043E-03	4.093E-03	3.156E-03	2.823E-03	2.340E-03	1.703E-03	1.058E-03	4.961E-04	1.393E-04	5.888E-04	—	—	—	—	—
12	0.9777	6.450E-03	3.742E-03	2.821E-03	2.482E-03	2.218E-03	1.730E-03	1.230E-03	7.357E-04	3.272E-04	9.340E-05	5.006E-04	—	—	—	—
13	0.9787	5.898E-03	3.478E-03	2.581E-03	2.168E-03	2.042E-03	1.721E-03	1.278E-03	9.147E-04	5.112E-04	2.202E-04	6.525E-05	4.379E-04	—	—	—
14	0.9796	5.442E-03	3.243E-03	2.403E-03	1.946E-03	1.765E-03	1.744E-03	1.248E-03	9.988E-04	6.809E-04	3.533E-04	1.530E-04	4.712E-05	4.144E-04	—	—
15	0.9804	5.067E-03	3.022E-03	2.273E-03	1.767E-03	1.601E-03	1.549E-03	1.321E-03	9.659E-04	8.094E-04	4.934E-04	2.460E-04	1.107E-04	3.475E-05	3.762E-04	—
16	0.9810	4.759E-03	2.806E-03	2.179E-03	1.623E-03	1.453E-03	1.391E-03	1.279E-03	1.025E-03	7.483E-04	6.894E-04	3.261E-04	1.827E-04	8.177E-05	2.605E-05	3.864E-04



Name: CCF2015VALVEEX
Independent Event Count: 2056.800
Average CCCG Size: 5.850
Description: 1997-2015, exclude LS

CCCG Size	Sum of N	Adj. Ind. Events	N1	N2	N3	N4	N5	N6	N7
2	781.8815	703.18	51.0500	27.6520					
3	1141.1652	1054.77	46.4200	30.6560	9.3200				
4	1502.7560	1406.36	40.9600	35.3790	13.5630	6.4950			
5	1860.1827	1757.95	39.7700	32.8290	18.3090	7.9400	3.3860		
6	2218.6815	2109.54	39.2700	29.8290	20.5160	11.4540	4.8490	3.2250	
7	2575.4742	2461.13	39.5000	28.1570	19.0250	14.1470	8.0990	2.9010	2.517
8	2933.3360	2812.72	39.1100	27.8740	17.6690	14.1160	10.8440	5.5080	1.728
9	3287.7337	3164.31	38.6500	27.8850	16.7250	13.9590	11.2850	7.6720	3.903
10	3643.1128	3515.90	37.9600	28.0070	16.3490	13.3210	11.4660	8.7660	5.639
11	3998.3296	3867.49	37.1100	28.1640	16.3680	12.6210	11.2880	9.3560	6.809
12	4352.8142	4219.08	36.5300	28.0810	16.2900	12.2790	10.8050	9.6540	7.530
13	4707.0751	4570.67	36.0700	27.7650	16.3740	12.1490	10.2040	9.6130	8.100
14	5061.2580	4922.26	35.5400	27.5480	16.4160	12.1640	9.8530	8.9350	8.828

Figure 4-3. Input to the CalcPrior code for estimating CCF prior distributions (valve, distinguishing lethal shocks from non-lethal shocks).



Param Name	CCCG Size : 2	CCCG Size : 3	CCCG Size : 4	CCCG Size : 5	CCCG Size : 6	CCCG Size : 7
a1	1.2105E+001	3.0793E+001	4.7655E+001	7.7670E+001	1.0346E+002	1.4082E+002
b1	4.4382E-001	1.1179E+000	1.8253E+000	2.6987E+000	3.3642E+000	4.2150E+000
a2	4.4382E-001	8.5726E-001	1.1649E+000	1.4184E+000	1.4362E+000	1.5857E+000
b2	1.2105E+001	3.1054E+001	4.8315E+001	7.8950E+001	1.0539E+002	1.4345E+002
a3		2.6062E-001	4.4658E-001	7.9104E-001	9.8779E-001	1.0714E+000
b3		3.1651E+001	4.9034E+001	7.9578E+001	1.0584E+002	1.4397E+002
a4			2.1386E-001	3.4305E-001	5.5148E-001	7.9669E-001
b4			4.9267E+001	8.0026E+001	1.0627E+002	1.4424E+002
a5				1.4629E-001	2.3347E-001	4.5610E-001
b5				8.0222E+001	1.0659E+002	1.4458E+002
a6					1.5527E-001	1.6337E-001
b6					1.0667E+002	1.4488E+002
a7						1.4175E-001
b7						1.4490E+002
a8						
b8						
a9						
b9						
a10						
b10						
a11						

● Geometric Mean ○ Arithmetic Mean

Figure 4-4. CCF prior distribution parameters calculated by the CalcPrior code (valve, distinguishing lethal shocks from non-lethal shocks).

Table 4-10. Estimated industry-wide alpha factor prior distributions (valve, distinguishing lethal shocks from non-lethal shocks).

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	1.21E+01	4.44E-01	4.44E-01	1.21E+01	—	—	—	—	—	—	—	—	—	—	—	—
3	3.08E+01	1.12E+00	8.57E-01	3.11E+01	2.61E-01	3.17E+01	—	—	—	—	—	—	—	—	—	—
4	4.77E+01	1.83E+00	1.16E+00	4.83E+01	4.47E-01	4.90E+01	2.14E-01	4.93E+01	—	—	—	—	—	—	—	—
5	7.77E+01	2.70E+00	1.42E+00	7.90E+01	7.91E-01	7.96E+01	3.43E-01	8.00E+01	1.46E-01	8.02E+01	—	—	—	—	—	—
6	1.03E+02	3.36E+00	1.44E+00	1.05E+02	9.88E-01	1.06E+02	5.51E-01	1.06E+02	2.33E-01	1.07E+02	1.55E-01	1.07E+02	—	—	—	—
7	1.41E+02	4.22E+00	1.59E+00	1.43E+02	1.07E+00	1.44E+02	7.97E-01	1.44E+02	4.56E-01	1.45E+02	1.63E-01	1.45E+02	1.42E-01	1.45E+02	—	—
8	1.70E+02	4.85E+00	1.66E+00	1.73E+02	1.05E+00	1.74E+02	8.41E-01	1.74E+02	6.46E-01	1.74E+02	3.28E-01	1.74E+02	1.03E-01	1.75E+02	2.24E-01	1.74E+02
9	2.28E+02	6.02E+00	1.98E+00	2.32E+02	1.19E+00	2.32E+02	9.92E-01	2.33E+02	8.02E-01	2.33E+02	5.45E-01	2.33E+02	2.77E-01	2.33E+02	8.19E-02	2.34E+02
10	2.79E+02	7.00E+00	2.20E+00	2.83E+02	1.28E+00	2.84E+02	1.04E+00	2.85E+02	8.99E-01	2.85E+02	6.87E-01	2.85E+02	4.42E-01	2.85E+02	2.18E-01	2.85E+02
11	3.32E+02	7.97E+00	2.39E+00	3.38E+02	1.39E+00	3.39E+02	1.07E+00	3.39E+02	9.60E-01	3.39E+02	7.96E-01	3.39E+02	5.79E-01	3.39E+02	3.60E-01	3.40E+02
12	3.98E+02	9.09E+00	2.63E+00	4.04E+02	1.52E+00	4.06E+02	1.15E+00	4.06E+02	1.01E+00	4.06E+02	9.03E-01	4.06E+02	7.04E-01	4.06E+02	5.01E-01	4.07E+02
13	4.70E+02	1.02E+01	2.83E+00	4.78E+02	1.67E+00	4.79E+02	1.24E+00	4.79E+02	1.04E+00	4.79E+02	9.81E-01	4.79E+02	8.27E-01	4.80E+02	6.14E-01	4.80E+02
14	5.46E+02	1.14E+01	3.03E+00	5.55E+02	1.81E+00	5.56E+02	1.34E+00	5.56E+02	1.09E+00	5.56E+02	9.84E-01	5.57E+02	9.73E-01	5.57E+02	6.96E-01	5.57E+02
15	8.39E+02	1.65E+01	4.34E+00	8.51E+02	2.59E+00	8.53E+02	1.95E+00	8.54E+02	1.51E+00	8.54E+02	1.37E+00	8.54E+02	1.33E+00	8.54E+02	1.13E+00	8.54E+02
16	8.35E+02	1.58E+01	4.05E+00	8.46E+02	2.39E+00	8.48E+02	1.85E+00	8.49E+02	1.38E+00	8.49E+02	1.24E+00	8.49E+02	1.18E+00	8.49E+02	1.09E+00	8.49E+02

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	1.56E-01	2.33E+02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	6.19E-02	2.86E+02	1.68E-01	2.85E+02	—	—	—	—	—	—	—	—	—	—	—	—
11	1.69E-01	3.40E+02	4.74E-02	3.40E+02	2.00E-01	3.40E+02	—	—	—	—	—	—	—	—	—	—
12	3.00E-01	4.07E+02	1.33E-01	4.07E+02	3.80E-02	4.07E+02	2.04E-01	4.07E+02	—	—	—	—	—	—	—	—
13	4.39E-01	4.80E+02	2.46E-01	4.80E+02	1.06E-01	4.80E+02	3.13E-02	4.80E+02	2.10E-01	4.80E+02	—	—	—	—	—	—
14	5.57E-01	5.57E+02	3.80E-01	5.57E+02	1.97E-01	5.57E+02	8.53E-02	5.57E+02	2.63E-02	5.58E+02	2.31E-01	5.57E+02	—	—	—	—
15	8.27E-01	8.55E+02	6.93E-01	8.55E+02	4.22E-01	8.55E+02	2.11E-01	8.55E+02	9.48E-02	8.55E+02	2.97E-02	8.56E+02	5.91E-03	8.56E+02	—	—
16	8.72E-01	8.49E+02	6.37E-01	8.50E+02	5.87E-01	8.50E+02	2.77E-01	8.50E+02	1.55E-01	8.50E+02	6.96E-02	8.50E+02	2.22E-02	8.50E+02	3.38E-02	8.50E+02

5. DEVELOPING PRIOR DISTRIBUTIONS OF ALPHA FACTORS SPECIFIC TO STRAINER COMPONENTS

This section presents the development of the prior distributions of alpha factors specific to strainer components. As no strainer lethal shock events occurred during the study period, no sensitivity study subsection is included in this section.

5.1 Accessing CCF Data

To estimate the prior distributions for the strainer component type, the following selection criteria are defined on the NRC RADS CCF database website:

- Type of CCF Event Level: All Level CCF Events
- CCF Event Type: CCF Events Only
- Date Range: 1997–2015
- Filter Independent Events by Selected Cause(s): True
- Shock Criteria: All Events
- Redundancy Range: Minimum = 2, Maximum = 16
- Bayesian Update Method: Mean Method
- Failure Modes: select all failure modes except Setpoint
- CCF Categories: Components → Filter → Strainer.

A total of 51 CCF events and 309.2 effective independent failure events related to the above selection criteria. Table 5-1 shows the number of partial CCF events, the number of complete CCF events, and the total number of CCF events. Table 5-2 shows the mapped impact vectors for partial CCF events pertaining to each group size (2–16), as obtained from the CCF database website.

Table 5-1. CCF data (strainer).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events
2	1	10	11
3	3	4	7
4	8	1	9
5	1	0	1
6	12	5	17
7	1	0	1
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	5	0	5
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
Total	31	20	51

Table 5-2. n_k values for partial CCF events (strainer).

Group Size	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	17.68	5.229	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	15.48	11.042	1.549	—	—	—	—	—	—	—	—	—	—	—	—	—
4	11.85	13.811	4.890	0.483	—	—	—	—	—	—	—	—	—	—	—	—
5	10.16	12.445	7.968	2.270	0.223	—	—	—	—	—	—	—	—	—	—	—
6	9.51	9.517	10.319	4.093	1.069	0.144	—	—	—	—	—	—	—	—	—	—
7	9.92	8.057	8.987	5.589	2.696	0.726	0.093	—	—	—	—	—	—	—	—	—
8	10.19	7.449	7.443	6.238	3.605	1.858	0.497	0.060	—	—	—	—	—	—	—	—
9	10.34	7.148	6.340	6.178	4.225	2.575	1.307	0.341	0.039	—	—	—	—	—	—	—
10	10.36	7.096	5.476	5.886	4.533	3.053	1.932	0.929	0.234	0.0253	—	—	—	—	—	—
11	10.26	7.278	4.698	5.600	4.576	3.397	2.331	1.480	0.665	0.1608	0.0165	—	—	—	—	—
12	10.01	7.710	3.883	5.433	4.436	3.620	2.610	1.852	1.139	0.4767	0.1105	0.0108	—	—	—	—
13	10.42	7.185	3.866	4.721	4.466	3.718	2.832	2.088	1.501	0.8755	0.3424	0.0759	0.0070	—	—	—
14	10.81	6.748	3.856	4.181	4.303	3.779	3.004	2.263	1.728	1.2229	0.6699	0.2459	0.0521	0.0046	—	—
15	11.19	6.384	3.845	3.776	4.052	3.768	3.136	2.418	1.872	1.4582	0.9932	0.5101	0.1766	0.0358	0.0030	v
16	11.55	6.080	3.828	3.475	3.772	3.686	3.218	2.562	1.986	1.5963	1.2378	0.8011	0.3865	0.1266	0.0245	0.0020

5.2 Treating Complete CCF Events

This section presents the curve-fitting results for the fraction of complete CCF events over the total number of CCF events for the strainer components. The results are listed in the last two columns of Table 5-3. A review of the strainer CCF data found no CCF events coded as lethal shock events. Hence, no sensitivity study was conducted to examine the impacts of distinguishing lethal shocks from non-lethal-shock-but-complete-CCF events.

Table 5-3. CCF data with curve-fitted complete CCF events (strainer).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events	Prob. of Complete CCF Event - Data	Prob. of Complete CCF Event - Curve Fitting	Estimated No. Complete CCF Events
2	1	10	11	0.909	0.912	10.037
3	3	4	7	0.571	0.463	3.244
4	8	1	9	0.111	0.257	2.311
5	1	0	1	0.000	0.198	0.198
6	12	5	17	0.294	0.179	3.041
7	1	0	1	0.000	0.172	0.172
8	0	0	0	NA	0.170	0.000
9	0	0	0	NA	0.169	0.000
10	0	0	0	NA	0.169	0.000
11	0	0	0	NA	0.169	0.000

Table 5-3. (continued).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events	Prob. of Complete CCF Event - Data	Prob. of Complete CCF Event - Curve Fitting	Estimated No. Complete CCF Events
12	5	0	5	0.000	0.169	0.843
13	0	0	0	NA	0.169	0.000
14	0	0	0	NA	0.169	0.000
15	0	0	0	NA	0.169	0.000
16	0	0	0	NA	0.169	0.000
Total	31	20	51	—	—	19.847

5.3 Estimating Prior Distributions

Adjusted n_k values for strainer CCF events were obtained for each group size by adding the estimated number of complete CCF events in Table 5-3 to the final n_k value for the partial CCF events in Table 5-2. Table 5-4 shows the adjusted n_k results, as well as the n_I and n_t results, of the strainer CCF data for group sizes 2–16. The calculated MLEs (i.e., alpha factor mean values) for each group size are presented in Table 5-5.

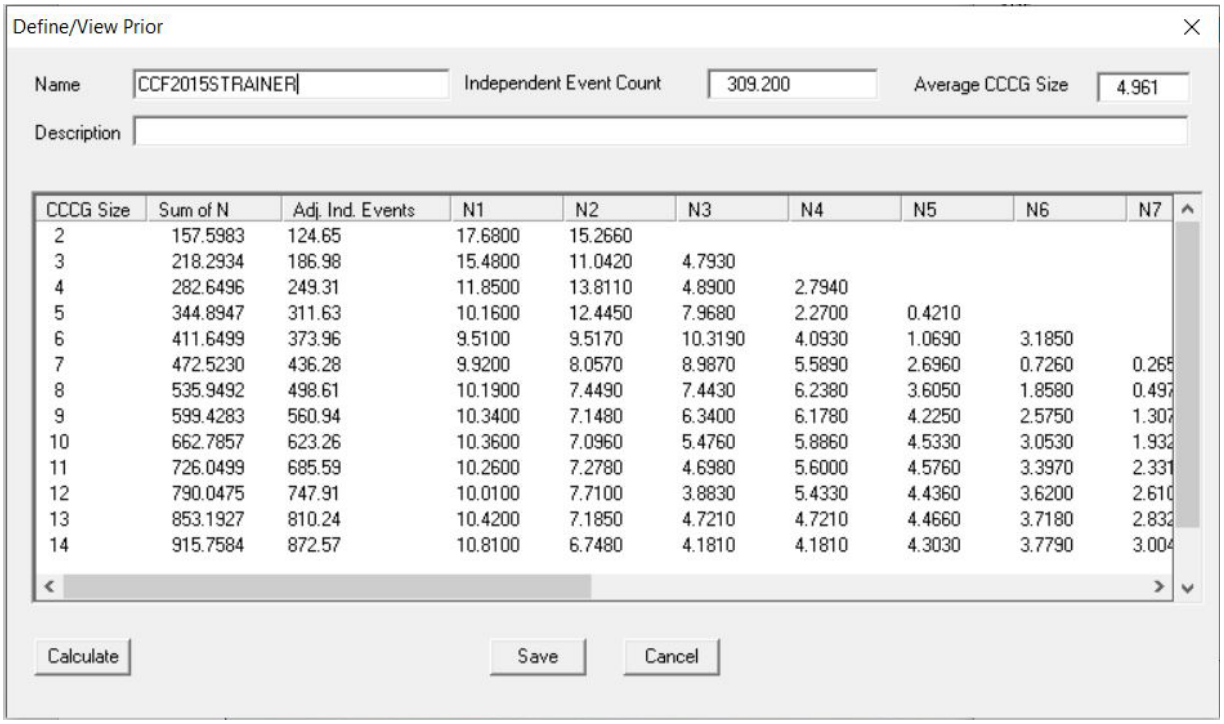
Adjusted n_k and n_I values were input to the computer code CalcPrior to estimate the industry-wide prior distributions with parameters α and β. Figure 5-1 shows the code's needed input for calculating the prior distributions. Figure 5-2 shows the CalcPrior results for the prior distribution parameters, which were then output to Table 5-6.

Table 5-4. Adjusted n_k values for all CCF events (strainer).

Group Size	n_t	n_I	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	157.61	124.66	17.68	15.266	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	218.31	186.99	15.48	11.042	4.793	—	—	—	—	—	—	—	—	—	—	—	—	—
4	282.67	249.32	11.85	13.811	4.890	2.794	—	—	—	—	—	—	—	—	—	—	—	—
5	344.90	311.64	10.16	12.445	7.968	2.270	0.421	—	—	—	—	—	—	—	—	—	—	—
6	411.66	373.97	9.51	9.517	10.319	4.093	1.069	3.185	—	—	—	—	—	—	—	—	—	—
7	472.54	436.30	9.92	8.057	8.987	5.589	2.696	0.726	0.265	—	—	—	—	—	—	—	—	—
8	535.97	498.63	10.19	7.449	7.443	6.238	3.605	1.858	0.497	0.060	—	—	—	—	—	—	—	—
9	599.45	560.96	10.34	7.148	6.340	6.178	4.225	2.575	1.307	0.341	0.039	—	—	—	—	—	—	—
10	662.81	623.29	10.36	7.096	5.476	5.886	4.533	3.053	1.932	0.929	0.234	0.0253	—	—	—	—	—	—
11	726.08	685.62	10.26	7.278	4.698	5.600	4.576	3.397	2.331	1.480	0.665	0.1608	0.0165	—	—	—	—	—
12	790.08	747.95	10.01	7.710	3.883	5.433	4.436	3.620	2.610	1.852	1.139	0.4767	0.1105	0.8536	—	—	—	—
13	852.38	810.28	10.42	7.185	3.866	4.721	4.466	3.718	2.832	2.088	1.501	0.8755	0.3424	0.0759	0.0070	—	—	—
14	915.47	872.60	10.81	6.748	3.856	4.181	4.303	3.779	3.004	2.263	1.728	1.2229	0.6699	0.2459	0.0521	0.0046	—	—
15	978.55	934.93	11.19	6.384	3.845	3.776	4.052	3.768	3.136	2.418	1.872	1.4582	0.9932	0.5101	0.1766	0.0358	0.0030	—
16	1041.59	997.26	11.55	6.080	3.828	3.475	3.772	3.686	3.218	2.562	1.986	1.5963	1.2378	0.8011	0.3865	0.1266	0.0245	0.0020

Table 5-5. Calculated alpha factor mean values for CCF events (strainer).

Group Size	$\boldsymbol{\alpha_1}$	$\boldsymbol{\alpha_2}$	$\boldsymbol{\alpha_3}$	$\boldsymbol{\alpha_4}$	$\boldsymbol{\alpha_5}$	$\boldsymbol{\alpha_6}$	$\boldsymbol{\alpha_7}$	$\boldsymbol{\alpha_8}$	$\boldsymbol{\alpha_9}$	$\boldsymbol{\alpha_{10}}$	$\boldsymbol{\alpha_{11}}$	$\boldsymbol{\alpha_{12}}$	$\boldsymbol{\alpha_{13}}$	$\boldsymbol{\alpha_{14}}$	$\boldsymbol{\alpha_{15}}$	$\boldsymbol{\alpha_{16}}$
2	0.9031	9.686E-02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9275	5.058E-02	2.196E-02	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9240	4.886E-02	1.730E-02	9.884E-03	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9330	3.608E-02	2.310E-02	6.582E-03	1.221E-03	—	—	—	—	—	—	—	—	—	—	—
6	0.9315	2.312E-02	2.507E-02	9.943E-03	2.597E-03	7.737E-03	—	—	—	—	—	—	—	—	—	—
7	0.9443	1.705E-02	1.902E-02	1.183E-02	5.705E-03	1.536E-03	5.608E-04	—	—	—	—	—	—	—	—	—
8	0.9493	1.390E-02	1.389E-02	1.164E-02	6.726E-03	3.467E-03	9.273E-04	1.119E-04	—	—	—	—	—	—	—	—
9	0.9530	1.192E-02	1.058E-02	1.031E-02	7.048E-03	4.296E-03	2.180E-03	5.689E-04	6.506E-05	—	—	—	—	—	—	—
10	0.9560	1.071E-02	8.262E-03	8.880E-03	6.839E-03	4.606E-03	2.915E-03	1.402E-03	3.530E-04	3.817E-05	—	—	—	—	—	—
11	0.9584	1.002E-02	6.470E-03	7.713E-03	6.302E-03	4.679E-03	3.210E-03	2.038E-03	9.159E-04	2.215E-04	2.272E-05	—	—	—	—	—
12	0.9593	9.758E-03	4.915E-03	6.876E-03	5.615E-03	4.582E-03	3.303E-03	2.344E-03	1.442E-03	6.034E-04	1.399E-04	1.080E-03	—	—	—	—
13	0.9628	8.429E-03	4.536E-03	5.539E-03	5.239E-03	4.362E-03	3.322E-03	2.450E-03	1.761E-03	1.027E-03	4.017E-04	8.905E-05	8.212E-06	—	—	—
14	0.9650	7.371E-03	4.212E-03	4.567E-03	4.700E-03	4.128E-03	3.281E-03	2.472E-03	1.888E-03	1.336E-03	7.318E-04	2.686E-04	5.691E-05	5.025E-06	—	—
15	0.9669	6.524E-03	3.929E-03	3.859E-03	4.141E-03	3.851E-03	3.205E-03	2.471E-03	1.913E-03	1.490E-03	1.015E-03	5.213E-04	1.805E-04	3.658E-05	3.066E-06	—
16	0.9685	5.837E-03	3.675E-03	3.336E-03	3.621E-03	3.539E-03	3.090E-03	2.460E-03	1.907E-03	1.533E-03	1.188E-03	7.691E-04	3.711E-04	1.215E-04	2.352E-05	1.920E-06



Name: CCF2015STRAINER

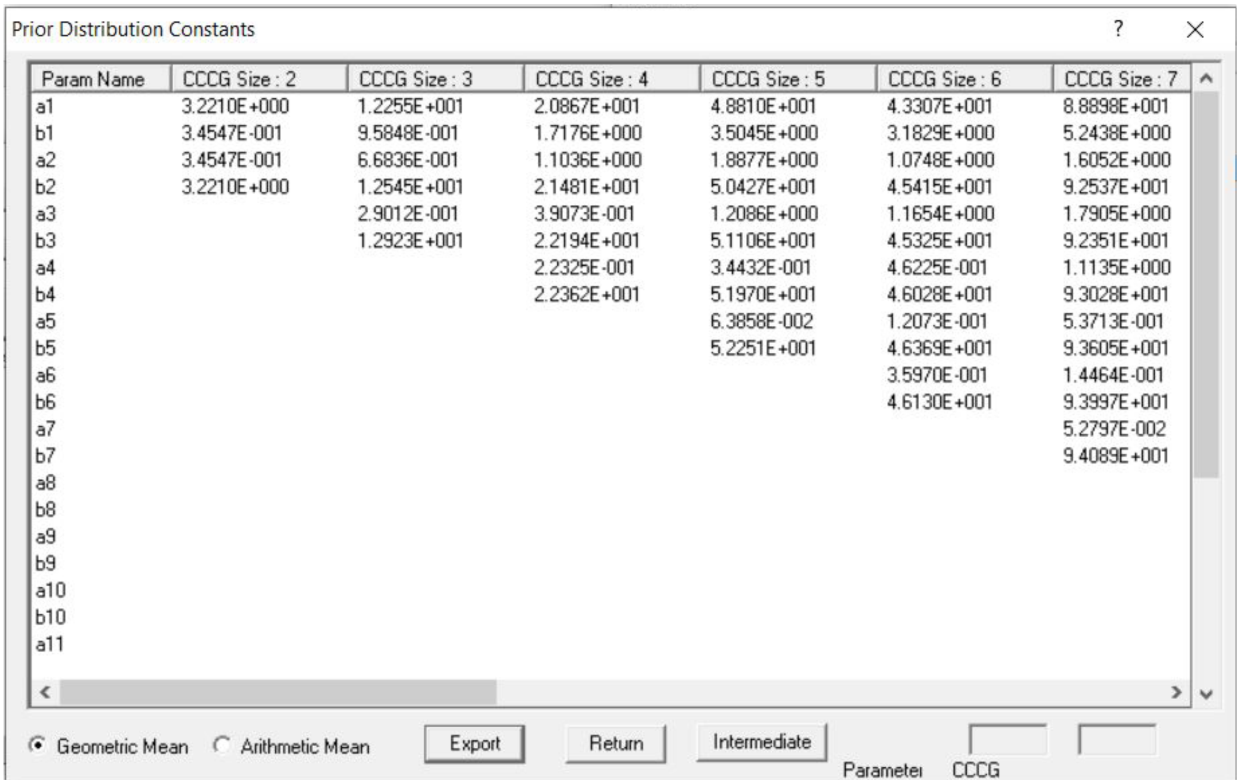
Independent Event Count: 309.200

Average CCCG Size: 4.961

Description:

CCCG Size	Sum of N	Adj. Ind. Events	N1	N2	N3	N4	N5	N6	N7
2	157.5983	124.65	17.6800	15.2660					
3	218.2934	186.98	15.4800	11.0420	4.7930				
4	282.6496	249.31	11.8500	13.8110	4.8900	2.7940			
5	344.8947	311.63	10.1600	12.4450	7.9680	2.2700	0.4210		
6	411.6499	373.96	9.5100	9.5170	10.3190	4.0930	1.0690	3.1850	
7	472.5230	436.28	9.9200	8.0570	8.9870	5.5890	2.6960	0.7260	0.265
8	535.9492	498.61	10.1900	7.4490	7.4430	6.2380	3.6050	1.8580	0.497
9	599.4283	560.94	10.3400	7.1480	6.3400	6.1780	4.2250	2.5750	1.307
10	662.7857	623.26	10.3600	7.0960	5.4760	5.8860	4.5330	3.0530	1.932
11	726.0499	685.59	10.2600	7.2780	4.6980	5.6000	4.5760	3.3970	2.331
12	790.0475	747.91	10.0100	7.7100	3.8830	5.4330	4.4360	3.6200	2.610
13	853.1927	810.24	10.4200	7.1850	4.7210	4.7210	4.4660	3.7180	2.832
14	915.7584	872.57	10.8100	6.7480	4.1810	4.1810	4.3030	3.7790	3.004

Figure 5-1. Input to the CalcPrior code for estimating CCF prior distributions (strainer).



● Geometric Mean ○ Arithmetic Mean

Param Name	CCCG Size : 2	CCCG Size : 3	CCCG Size : 4	CCCG Size : 5	CCCG Size : 6	CCCG Size : 7
a1	3.2210E+000	1.2255E+001	2.0867E+001	4.8810E+001	4.3307E+001	8.8898E+001
b1	3.4547E-001	9.5848E-001	1.7176E+000	3.5045E+000	3.1829E+000	5.2438E+000
a2	3.4547E-001	6.6836E-001	1.1036E+000	1.8877E+000	1.0748E+000	1.6052E+000
b2	3.2210E+000	1.2545E+001	2.1481E+001	5.0427E+001	4.5415E+001	9.2537E+001
a3		2.9012E-001	3.9073E-001	1.2086E+000	1.1654E+000	1.7905E+000
b3		1.2923E+001	2.2194E+001	5.1106E+001	4.5325E+001	9.2351E+001
a4			2.2325E-001	3.4432E-001	4.6225E-001	1.1135E+000
b4			2.2362E+001	5.1970E+001	4.6028E+001	9.3028E+001
a5				6.3858E-002	1.2073E-001	5.3713E-001
b5				5.2251E+001	4.6369E+001	9.3605E+001
a6					3.5970E-001	1.4464E-001
b6					4.6130E+001	9.3997E+001
a7						5.2797E-002
b7						9.4089E+001
a8						
b8						
a9						
b9						
a10						
b10						
a11						

Figure 5-2. CCF prior distribution parameters calculated by the CalcPrior code (strainer).

Table 5-6. Estimated industry-wide alpha factor prior distributions (strainer).

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	3.22E+00	3.45E-01	3.45E-01	3.22E+00	—	—	—	—	—	—	—	—	—	—	—	—
3	1.23E+01	9.58E-01	6.68E-01	1.25E+01	2.90E-01	1.29E+01	—	—	—	—	—	—	—	—	—	—
4	2.09E+01	1.72E+00	1.10E+00	2.15E+01	3.91E-01	2.22E+01	2.23E-01	2.24E+01	—	—	—	—	—	—	—	—
5	4.88E+01	3.50E+00	1.89E+00	5.04E+01	1.21E+00	5.11E+01	3.44E-01	5.20E+01	6.39E-02	5.23E+01	—	—	—	—	—	—
6	4.33E+01	3.18E+00	1.07E+00	4.54E+01	1.17E+00	4.53E+01	4.62E-01	4.60E+01	1.21E-01	4.64E+01	3.60E-01	4.61E+01	—	—	—	—
7	8.89E+01	5.24E+00	1.61E+00	9.25E+01	1.79E+00	9.24E+01	1.11E+00	9.30E+01	5.37E-01	9.36E+01	1.45E-01	9.40E+01	5.28E-02	9.41E+01	—	—
8	1.36E+02	7.25E+00	1.99E+00	1.41E+02	1.99E+00	1.41E+02	1.67E+00	1.41E+02	9.62E-01	1.42E+02	4.96E-01	1.43E+02	1.33E-01	1.43E+02	1.60E-02	1.43E+02
9	1.71E+02	8.42E+00	2.14E+00	1.77E+02	1.90E+00	1.77E+02	1.85E+00	1.77E+02	1.26E+00	1.78E+02	7.70E-01	1.78E+02	3.91E-01	1.79E+02	1.02E-01	1.79E+02
10	2.11E+02	9.72E+00	2.37E+00	2.19E+02	1.83E+00	2.19E+02	1.96E+00	2.19E+02	1.51E+00	2.19E+02	1.02E+00	2.20E+02	6.44E-01	2.20E+02	3.10E-01	2.21E+02
11	2.57E+02	1.12E+01	2.69E+00	2.66E+02	1.74E+00	2.67E+02	2.07E+00	2.66E+02	1.69E+00	2.67E+02	1.26E+00	2.67E+02	8.61E-01	2.67E+02	5.47E-01	2.68E+02
12	2.08E+02	8.82E+00	2.12E+00	2.15E+02	1.07E+00	2.16E+02	1.49E+00	2.15E+02	1.22E+00	2.16E+02	9.94E-01	2.16E+02	7.17E-01	2.16E+02	5.08E-01	2.16E+02
13	3.64E+02	1.44E+01	3.19E+00	3.75E+02	2.09E+00	3.76E+02	2.09E+00	3.76E+02	1.98E+00	3.76E+02	1.65E+00	3.77E+02	1.26E+00	3.77E+02	9.26E-01	3.77E+02
14	4.35E+02	1.60E+01	3.32E+00	4.48E+02	2.06E+00	4.49E+02	2.06E+00	4.49E+02	2.12E+00	4.49E+02	1.86E+00	4.49E+02	1.48E+00	4.50E+02	1.12E+00	4.50E+02
15	5.15E+02	1.76E+01	3.47E+00	5.29E+02	2.05E+00	5.30E+02	2.05E+00	5.30E+02	2.21E+00	5.30E+02	2.05E+00	5.30E+02	1.71E+00	5.31E+02	1.32E+00	5.31E+02
16	6.02E+02	1.94E+01	3.63E+00	6.18E+02	2.08E+00	6.20E+02	2.08E+00	6.20E+02	2.25E+00	6.20E+02	2.20E+00	6.20E+02	1.92E+00	6.20E+02	1.53E+00	6.20E+02

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	1.17E-02	1.79E+02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	7.80E-02	2.21E+02	8.43E-03	2.21E+02	—	—	—	—	—	—	—	—	—	—	—	—
11	2.46E-01	2.68E+02	5.94E-02	2.68E+02	6.10E-03	2.68E+02	—	—	—	—	—	—	—	—	—	—
12	3.13E-01	2.17E+02	1.31E-01	2.17E+02	3.03E-02	2.17E+02	2.34E-01	2.17E+02	—	—	—	—	—	—	—	—
13	6.66E-01	3.78E+02	3.88E-01	3.78E+02	1.52E-01	3.78E+02	3.37E-02	3.78E+02	3.10E-03	3.78E+02	—	—	—	—	—	—
14	8.51E-01	4.50E+02	6.03E-01	4.51E+02	3.30E-01	4.51E+02	1.21E-01	4.51E+02	2.57E-02	4.51E+02	2.27E-03	4.51E+02	—	—	—	—
15	1.02E+00	5.31E+02	7.94E-01	5.32E+02	5.41E-01	5.32E+02	2.78E-01	5.32E+02	9.61E-02	5.32E+02	1.95E-02	5.32E+02	1.63E-03	5.32E+02	—	—
16	1.19E+00	6.21E+02	9.53E-01	6.21E+02	7.39E-01	6.21E+02	4.78E-01	6.21E+02	2.31E-01	6.22E+02	7.56E-02	6.22E+02	1.46E-02	6.22E+02	1.19E-03	6.22E+02

6. DEVELOPING PRIOR DISTRIBUTIONS OF ALPHA FACTORS SPECIFIC TO GENERATOR COMPONENTS

This section develops the prior distributions of alpha factors specific to generator components. As no generator lethal shock events occurred during the study period, no sensitivity study subsection is included in this section.

6.1 Accessing CCF Data

To estimate the prior distributions for the generator component type, the following selection criteria are defined in the NRC RADS CCF database website.

- Type of CCF Event Level: All Level CCF Events
- CCF Event Type: CCF Events Only
- Date Range: 1997–2015
- Filter Independent Events by Selected Cause(s): True
- Shock Criteria: All Events
- Redundancy Range: Minimum = 2, Maximum = 16
- Bayesian Update Method: Mean Method
- Failure Modes: select all failure modes except Setpoint
- CCF Categories: Components → Emergency Power → Generator

A total of 15 CCF events and 925.7 effective independent failure events related to the above selection criteria. Table 6-1 shows the number of partial CCF events, the number of complete CCF events, and the total number of CCF events. Table 6-2 shows the mapped impact vectors for partial CCF events pertaining to each group size (2–16), as obtained from the CCF database website.

Table 6-1. CCF data (generator).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events
2	4	4	8
3	1	0	1
4	4	0	4
5	2	0	2
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
Total	11	4	15

Table 6-2. n_k values for partial CCF events (generator).

Group Size	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	7.53	0.989	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	8.43	2.862	0.035	—	—	—	—	—	—	—	—	—	—	—	—	—
4	8.88	4.037	0.624	0.004	—	—	—	—	—	—	—	—	—	—	—	—
5	9.96	3.865	1.444	0.267	0.000	—	—	—	—	—	—	—	—	—	—	—
6	10.77	4.018	1.766	0.646	0.128	0.000	—	—	—	—	—	—	—	—	—	—
7	11.35	4.369	1.916	0.923	0.333	0.063	0.000	—	—	—	—	—	—	—	—	—
8	11.73	4.817	2.040	1.090	0.531	0.182	0.031	0.000	—	—	—	—	—	—	—	—
9	11.95	5.297	2.195	1.185	0.683	0.321	0.102	0.016	0.000	—	—	—	—	—	—	—
10	12.04	5.771	2.395	1.248	0.786	0.447	0.198	0.057	0.008	0.000	—	—	—	—	—	—
11	12.03	6.215	2.638	1.308	0.848	0.547	0.298	0.122	0.032	0.004	0.000	—	—	—	—	—
12	11.94	6.616	2.916	1.383	0.885	0.619	0.387	0.199	0.075	0.018	0.002	0.0000	—	—	—	—
13	11.78	6.966	3.216	1.481	0.910	0.665	0.459	0.274	0.132	0.046	0.010	0.0010	0.0000	—	—	—
14	11.58	7.262	3.528	1.605	0.934	0.692	0.513	0.341	0.194	0.087	0.028	0.0054	0.0005	0.0000	—	—
15	11.34	7.506	3.841	1.755	0.965	0.707	0.550	0.396	0.253	0.136	0.056	0.0164	0.0029	0.0002	0.0000	—
16	11.08	7.699	4.149	1.929	1.009	0.714	0.573	0.439	0.306	0.187	0.094	0.0359	0.0096	0.0016	0.0001	0.0000

6.2 Treating Complete CCF Events

There is only one effective data point here, since all the others were discarded because either the number of total CCF events or the number of complete CCF events was zero. Thus, binomial regression cannot be performed for this component type, and the number of complete CCF events cannot be estimated from a fitted model.

6.3 Estimating Prior Distributions

Since binomial regression cannot be performed, Steps 1–4 of the method introduced in Section 1.2 are inapplicable. The prior distributions for the generator components were thus developed using Steps 5–7 only.

The mapped impact vectors for generator CCF events, as obtained from the NRC RADS website, were used directly in the study. Table 6-3 shows the adjusted n_k results, as well as the n_I and n_t results, of the generator CCF data for group sizes 2–16. The calculated MLEs (i.e., alpha factor mean values) for each group size are presented in Table 6-4.

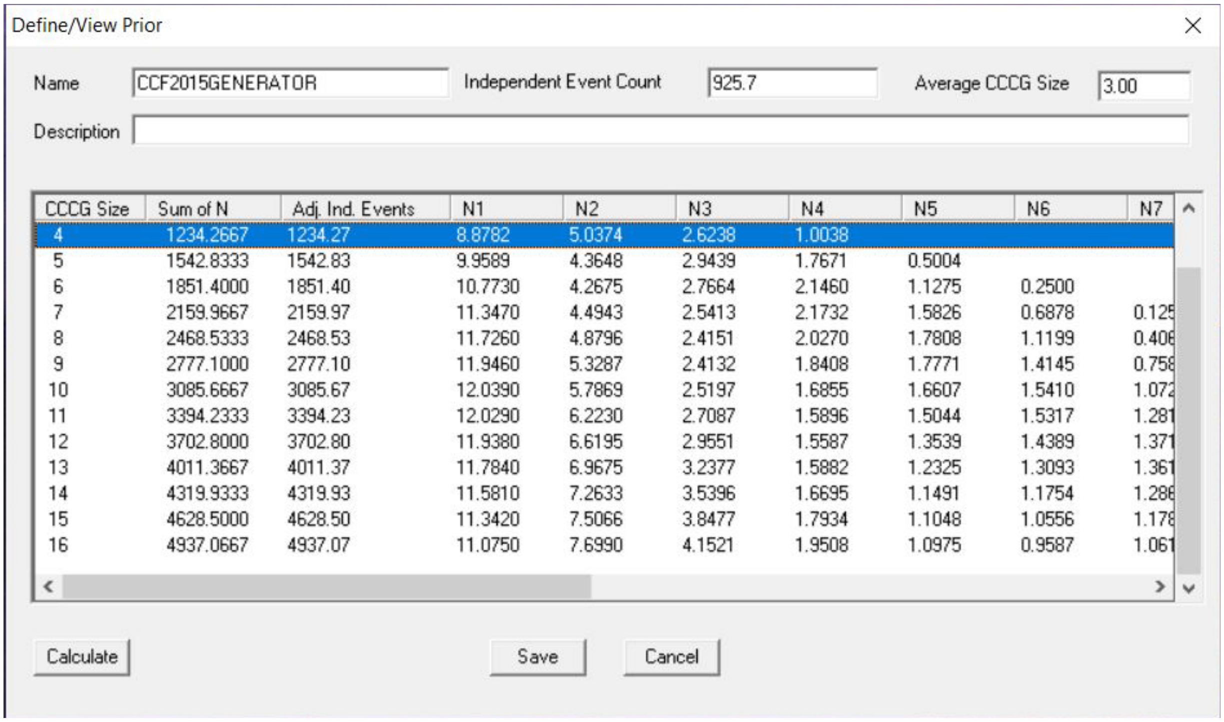
Adjusted n_k and n_I values were input to the computer code CalcPrior to estimate the industry-wide prior distributions with parameters α and β. Figure 6-1 shows the code's needed input for calculating the prior distributions. Figure 6-2 shows the CalcPrior results for the prior distribution parameters, which were then output to Table 6-5.

Table 6-3. Adjusted n_k values for all CCF events (generator).

Group Size	n_t	n_I	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	629.64	617.13	7.53	4.989	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	941.02	925.70	8.43	4.862	2.035	—	—	—	—	—	—	—	—	—	—	—	—	—
4	1251.81	1234.27	8.88	5.037	2.624	1.004	—	—	—	—	—	—	—	—	—	—	—	—
5	1562.37	1542.83	9.96	4.365	2.944	1.767	0.500	—	—	—	—	—	—	—	—	—	—	—
6	1872.73	1851.40	10.77	4.268	2.766	2.146	1.128	0.250	—	—	—	—	—	—	—	—	—	—
7	2182.92	2159.97	11.35	4.494	2.541	2.173	1.583	0.688	0.125	—	—	—	—	—	—	—	—	—
8	2492.95	2468.53	11.73	4.880	2.415	2.027	1.781	1.120	0.406	0.063	—	—	—	—	—	—	—	—
9	2802.84	2777.10	11.95	5.329	2.413	1.841	1.777	1.415	0.758	0.234	0.031	—	—	—	—	—	—	—
10	3112.62	3085.67	12.04	5.787	2.520	1.686	1.661	1.541	1.073	0.495	0.133	0.0156	—	—	—	—	—	—
11	3422.27	3394.23	12.03	6.223	2.709	1.590	1.504	1.532	1.282	0.779	0.313	0.0742	0.0078	—	—	—	—	—
12	3731.84	3702.80	11.94	6.620	2.955	1.559	1.354	1.439	1.371	1.019	0.544	0.1937	0.0410	0.0039	—	—	—	—
13	4041.31	4011.37	11.78	6.968	3.238	1.588	1.233	1.309	1.361	1.177	0.776	0.3681	0.1173	0.0225	0.0020	—	—	—
14	4350.70	4319.93	11.58	7.263	3.540	1.670	1.149	1.175	1.286	1.244	0.967	0.5701	0.2424	0.0699	0.0122	0.0010	—	—
15	4660.03	4628.50	11.34	7.507	3.848	1.793	1.105	1.056	1.178	1.234	1.091	0.7642	0.4053	0.1560	0.0410	0.0066	0.0005	—
16	4969.29	4937.07	11.08	7.699	4.152	1.951	1.098	0.959	1.062	1.172	1.144	0.9202	0.5827	0.2803	0.0985	0.0238	0.0035	0.0002

Table 6-4. Calculated alpha factor mean values (generator).

Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9921	7.923E-03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9927	5.166E-03	2.162E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9931	4.024E-03	2.096E-03	8.019E-04	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9939	2.794E-03	1.884E-03	1.131E-03	3.203E-04	—	—	—	—	—	—	—	—	—	—	—
6	0.9944	2.279E-03	1.477E-03	1.146E-03	6.021E-04	1.335E-04	—	—	—	—	—	—	—	—	—	—
7	0.9947	2.059E-03	1.164E-03	9.955E-04	7.250E-04	3.151E-04	5.727E-05	—	—	—	—	—	—	—	—	—
8	0.9949	1.957E-03	9.688E-04	8.131E-04	7.143E-04	4.492E-04	1.630E-04	2.507E-05	—	—	—	—	—	—	—	—
9	0.9951	1.901E-03	8.610E-04	6.568E-04	6.340E-04	5.047E-04	2.706E-04	8.362E-05	1.115E-05	—	—	—	—	—	—	—
10	0.9952	1.859E-03	8.095E-04	5.415E-04	5.335E-04	4.951E-04	3.447E-04	1.590E-04	4.267E-05	5.020E-06	—	—	—	—	—	—
11	0.9953	1.818E-03	7.915E-04	4.645E-04	4.396E-04	4.476E-04	3.746E-04	2.275E-04	9.158E-05	2.169E-05	2.283E-06	—	—	—	—	—
12	0.9954	1.774E-03	7.919E-04	4.177E-04	3.628E-04	3.856E-04	3.675E-04	2.731E-04	1.458E-04	5.190E-05	1.099E-05	1.047E-06	—	—	—	—
13	0.9955	1.724E-03	8.012E-04	3.930E-04	3.050E-04	3.240E-04	3.368E-04	2.912E-04	1.921E-04	9.107E-05	2.902E-05	5.558E-06	4.833E-07	—	—	—
14	0.9956	1.669E-03	8.136E-04	3.837E-04	2.641E-04	2.702E-04	2.956E-04	2.859E-04	2.223E-04	1.310E-04	5.571E-05	1.606E-05	2.806E-06	2.245E-07	—	—
15	0.9957	1.611E-03	8.257E-04	3.848E-04	2.371E-04	2.265E-04	2.528E-04	2.648E-04	2.342E-04	1.640E-04	8.698E-05	3.348E-05	8.804E-06	1.415E-06	1.048E-07	—
16	0.9957	1.549E-03	8.356E-04	3.926E-04	2.209E-04	1.929E-04	2.136E-04	2.358E-04	2.302E-04	1.852E-04	1.173E-04	5.640E-05	1.982E-05	4.791E-06	7.124E-07	4.913E-08



Name: CCF2015GENERATOR

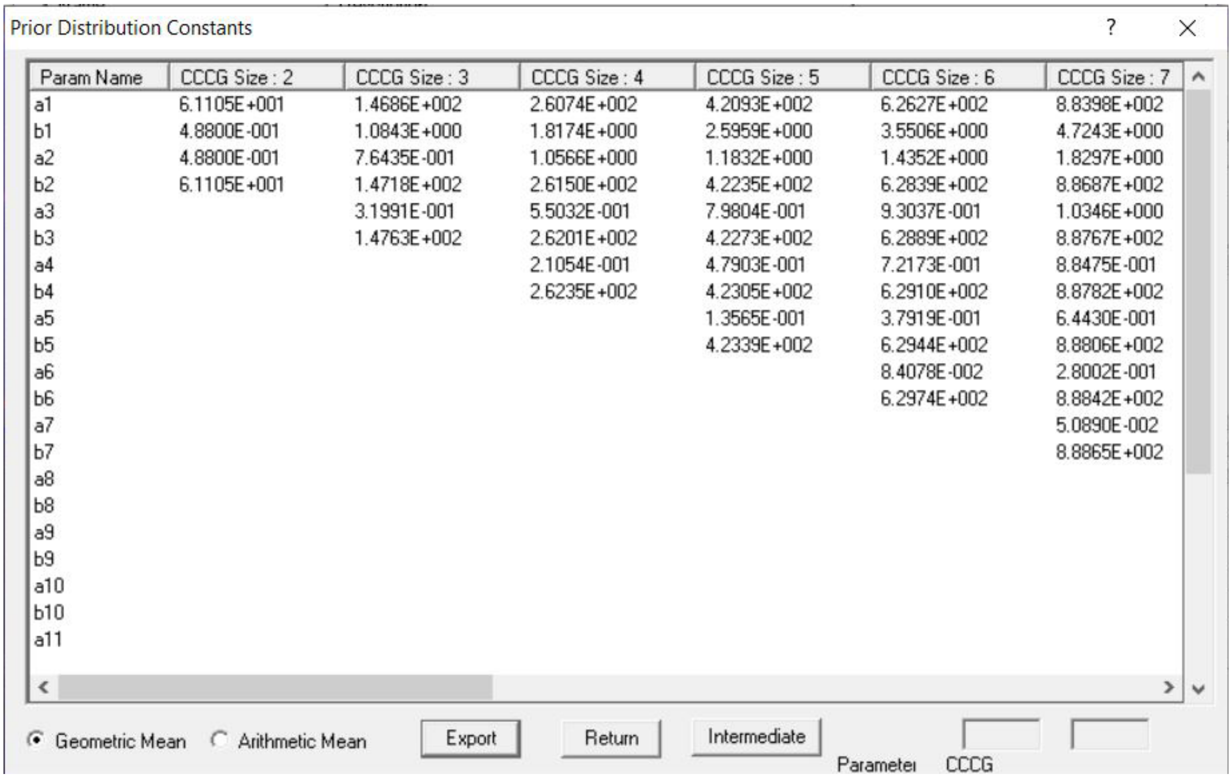
Independent Event Count: 925.7

Average CCCG Size: 3.00

Description:

CCCG Size	Sum of N	Adj. Ind. Events	N1	N2	N3	N4	N5	N6	N7
4	1234.2667	1234.27	8.8782	5.0374	2.6238	1.0038			
5	1542.8333	1542.83	9.9589	4.3648	2.9439	1.7671	0.5004		
6	1851.4000	1851.40	10.7730	4.2675	2.7664	2.1460	1.1275	0.2500	
7	2159.9667	2159.97	11.3470	4.4943	2.5413	2.1732	1.5826	0.6878	0.125
8	2468.5333	2468.53	11.7260	4.8796	2.4151	2.0270	1.7808	1.1199	0.406
9	2777.1000	2777.10	11.9460	5.3287	2.4132	1.8408	1.7771	1.4145	0.758
10	3085.6667	3085.67	12.0390	5.7869	2.5197	1.6855	1.6607	1.5410	1.072
11	3394.2333	3394.23	12.0290	6.2230	2.7087	1.5896	1.5044	1.5317	1.281
12	3702.8000	3702.80	11.9380	6.6195	2.9551	1.5587	1.3539	1.4389	1.371
13	4011.3667	4011.37	11.7840	6.9675	3.2377	1.5882	1.2325	1.3093	1.361
14	4319.9333	4319.93	11.5810	7.2633	3.5396	1.6695	1.1491	1.1754	1.286
15	4628.5000	4628.50	11.3420	7.5066	3.8477	1.7934	1.1048	1.0556	1.178
16	4937.0667	4937.07	11.0750	7.6990	4.1521	1.9508	1.0975	0.9587	1.061

Figure 6-1. Input to the CalcPrior code for estimating CCF prior distributions (generator).



Param Name	CCCG Size : 2	CCCG Size : 3	CCCG Size : 4	CCCG Size : 5	CCCG Size : 6	CCCG Size : 7
a1	6.1105E+001	1.4686E+002	2.6074E+002	4.2093E+002	6.2627E+002	8.8398E+002
b1	4.8800E-001	1.0843E+000	1.8174E+000	2.5959E+000	3.5506E+000	4.7243E+000
a2	4.8800E-001	7.6435E-001	1.0566E+000	1.1832E+000	1.4352E+000	1.8297E+000
b2	6.1105E+001	1.4718E+002	2.6150E+002	4.2235E+002	6.2839E+002	8.8687E+002
a3		3.1991E-001	5.5032E-001	7.9804E-001	9.3037E-001	1.0346E+000
b3		1.4763E+002	2.6201E+002	4.2273E+002	6.2889E+002	8.8767E+002
a4			2.1054E-001	4.7903E-001	7.2173E-001	8.8475E-001
b4			2.6235E+002	4.2305E+002	6.2910E+002	8.8782E+002
a5				1.3565E-001	3.7919E-001	6.4430E-001
b5				4.2339E+002	6.2944E+002	8.8806E+002
a6					8.4078E-002	2.8002E-001
b6					6.2974E+002	8.8842E+002
a7						5.0890E-002
b7						8.8865E+002
a8						
b8						
a9						
b9						
a10						
b10						
a11						

● Geometric Mean ○ Arithmetic Mean

Figure 6-2. CCF prior distribution parameters calculated by the CalcPrior code (generator).

Table 6-5. Estimated alpha factor prior distributions (generator).

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	6.11E+01	4.88E-01	4.88E-01	6.11E+01												
3	1.47E+02	1.08E+00	7.64E-01	1.47E+02	3.20E-01	1.48E+02										
4	2.61E+02	1.82E+00	1.06E+00	2.62E+02	5.50E-01	2.62E+02	2.11E-01	2.62E+02								
5	4.21E+02	2.60E+00	1.18E+00	4.22E+02	7.98E-01	4.23E+02	4.79E-01	4.23E+02	1.36E-01	4.23E+02						
6	6.26E+02	3.55E+00	1.44E+00	6.28E+02	9.30E-01	6.29E+02	7.22E-01	6.29E+02	3.79E-01	6.29E+02	8.41E-02	6.30E+02				
7	8.84E+02	4.72E+00	1.83E+00	8.87E+02	1.03E+00	8.88E+02	8.85E-01	8.88E+02	6.44E-01	8.88E+02	2.80E-01	8.88E+02	5.09E-02	8.89E+02		
8	1.20E+03	6.16E+00	2.37E+00	1.21E+03	1.17E+00	1.21E+03	9.84E-01	1.21E+03	8.65E-01	1.21E+03	5.44E-01	1.21E+03	1.97E-01	1.21E+03	3.03E-02	1.21E+03
9	1.60E+03	7.91E+00	3.05E+00	1.60E+03	1.38E+00	1.61E+03	1.06E+00	1.61E+03	1.02E+00	1.61E+03	8.11E-01	1.61E+03	4.35E-01	1.61E+03	1.34E-01	1.61E+03
10	2.08E+03	1.00E+01	3.89E+00	2.09E+03	1.69E+00	2.09E+03	1.13E+00	2.09E+03	1.12E+00	2.09E+03	1.04E+00	2.09E+03	7.21E-01	2.09E+03	3.32E-01	2.09E+03
11	2.67E+03	1.25E+01	4.87E+00	2.67E+03	2.12E+00	2.68E+03	1.24E+00	2.68E+03	1.18E+00	2.68E+03	1.20E+00	2.68E+03	1.00E+00	2.68E+03	6.09E-01	2.68E+03
12	3.37E+03	1.55E+01	6.01E+00	3.38E+03	2.68E+00	3.38E+03	1.41E+00	3.39E+03	1.23E+00	3.39E+03	1.31E+00	3.39E+03	1.24E+00	3.39E+03	9.25E-01	3.39E+03
13	4.23E+03	1.91E+01	7.33E+00	4.24E+03	3.40E+00	4.25E+03	1.67E+00	4.25E+03	1.30E+00	4.25E+03	1.38E+00	4.25E+03	1.43E+00	4.25E+03	1.24E+00	4.25E+03
14	5.22E+03	2.31E+01	8.76E+00	5.24E+03	4.27E+00	5.24E+03	2.01E+00	5.25E+03	1.39E+00	5.25E+03	1.42E+00	5.25E+03	1.55E+00	5.25E+03	1.50E+00	5.25E+03
15	6.43E+03	2.80E+01	1.04E+01	6.45E+03	5.33E+00	6.45E+03	2.48E+00	6.45E+03	1.53E+00	6.46E+03	1.46E+00	6.46E+03	1.63E+00	6.46E+03	1.71E+00	6.46E+03
16	7.99E+03	3.41E+01	1.24E+01	8.01E+03	6.70E+00	8.01E+03	3.15E+00	8.02E+03	1.77E+00	8.02E+03	1.55E+00	8.02E+03	1.71E+00	8.02E+03	1.89E+00	8.02E+03

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	1.79E-02	1.61E+03														
10	8.92E-02	2.09E+03	1.05E-02	2.09E+03												
11	2.45E-01	2.68E+03	5.81E-02	2.68E+03	6.10E-03	2.68E+03										
12	4.94E-01	3.39E+03	1.76E-01	3.39E+03	3.72E-02	3.39E+03	3.54E-03	3.39E+03								
13	8.16E-01	4.25E+03	3.87E-01	4.25E+03	1.23E-01	4.25E+03	2.36E-02	4.25E+03	2.00E-03	4.25E+03						
14	1.17E+00	5.25E+03	6.87E-01	5.25E+03	2.92E-01	5.25E+03	8.42E-02	5.25E+03	1.47E-02	5.25E+03	1.21E-03	5.25E+03				
15	1.51E+00	6.46E+03	1.06E+00	6.46E+03	5.62E-01	6.46E+03	2.16E-01	6.46E+03	5.68E-02	6.46E+03	9.14E-03	6.46E+03	6.93E-04	6.46E+03		
16	1.85E+00	8.02E+03	1.48E+00	8.02E+03	9.40E-01	8.02E+03	4.52E-01	8.02E+03	1.59E-01	8.02E+03	3.84E-02	8.02E+03	5.65E-03	8.02E+03	3.23E-04	8.02E+03

7. DEVELOPING PRIOR DISTRIBUTIONS OF ALPHA FACTORS SPECIFIC TO “OTHER” COMPONENTS

This section presents the development of the prior distributions of alpha factors specific to components in the “other” category.

7.1 Accessing CCF Data

To estimate the prior distributions for the “other” component type, the following selection criteria are defined in the NRC RADS CCF database website.

- Type of CCF Event Level: All Level CCF Events
- CCF Event Type: CCF Events Only
- Date Range: 1997–2015
- Filter Independent Events by Selected Cause(s): True
- Shock Criteria: All Events
- Redundancy Range: Minimum = 2, Maximum = 16
- Bayesian Update Method: Mean Method
- Failure Modes: select all failure modes except Setpoint
- CCF Categories: Components → all component types other than pump, valve, strainer, and generator.

A total of 33 CCF events and 2334.0 effective independent failure events related to the above selection criteria. Table 7-1 shows the number of partial CCF events, the number of complete CCF events, and the total number of CCF events. Table 7-2 shows the mapped impact vectors for partial CCF events pertaining to each group size (2–16), as obtained from the CCF database website.

Table 7-1. CCF data (other).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events
2	3	4	7
3	2	1	3
4	8	0	8
5	0	0	0
6	6	0	6
7	0	0	0
8	1	0	1
9	0	0	0
10	0	0	0
11	0	0	0
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0
16	7	0	7
Total	27	6	33

Table 7-2. n_k values for partial CCF events (other).

Group Size	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	13.23	2.621	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	12.77	7.070	0.264	—	—	—	—	—	—	—	—	—	—	—	—	—
4	10.83	10.311	1.553	0.126	—	—	—	—	—	—	—	—	—	—	—	—
5	11.53	8.809	3.904	0.815	0.063	—	—	—	—	—	—	—	—	—	—	—
6	11.75	8.369	4.565	1.925	0.438	0.031	—	—	—	—	—	—	—	—	—	—
7	12.50	7.430	4.869	2.753	1.058	0.234	0.016	—	—	—	—	—	—	—	—	—
8	13.09	6.993	4.740	3.256	1.686	0.607	0.125	0.008	—	—	—	—	—	—	—	—
9	13.83	6.474	4.601	3.469	2.190	1.051	0.353	0.066	0.004	—	—	—	—	—	—	—
10	14.49	6.180	4.404	3.501	2.529	1.474	0.663	0.206	0.035	0.002	—	—	—	—	—	—
11	15.09	6.036	4.219	3.424	2.716	1.819	0.996	0.419	0.119	0.019	0.001	—	—	—	—	—
12	15.63	5.988	4.077	3.292	2.787	2.068	1.304	0.674	0.263	0.068	0.010	0.0005	—	—	—	—
13	16.12	5.998	3.989	3.141	2.776	2.224	1.558	0.934	0.453	0.163	0.039	0.0051	0.0002	—	—	—
14	16.57	6.038	3.957	2.990	2.717	2.302	1.749	1.169	0.665	0.302	0.100	0.0220	0.0027	0.0001	—	—
15	16.99	6.087	3.980	2.848	2.631	2.322	1.878	1.365	0.874	0.470	0.198	0.0607	0.0123	0.0014	0.0001	—
16	17.39	6.130	4.054	2.719	2.536	2.302	1.954	1.515	1.061	0.649	0.328	0.1284	0.0364	0.0068	0.0007	0.0000

7.2 Treating Complete CCF Events

This section presents the curve-fitting results for the fraction of complete CCF events over the total number of CCF events for the “other” components. The results are listed in the last two columns of Table 7-3. A review of the “other” CCF data found one CCF event coded as a lethal shock event, corresponding to a group size of 2. Sensitivity studies were conducted to examine the impacts of distinguishing lethal shocks from non-lethal-shock-but-complete-CCF events. The sensitivity analysis results are presented in Section 7.4.

Table 7-3. CCF data with curve-fitted complete CCF events (other).

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events	Prob. of Complete CCF Event - Data	Prob. of Complete CCF Event - Curve Fitting	Estimated No. Complete CCF Events
2	3	4	7	0.571	0.571	4.000
3	2	1	3	0.333	0.333	1.000
4	8	0	8	0000	0.258	2.068
5	0	0	0	NA	0.234	0.000
6	6	0	6	0.000	0.225	1.351
7	0	0	0	NA	0.222	0.000
8	1	0	1	0.000	0.221	0.221
9	0	0	0	NA	0.221	0.000
10	0	0	0	NA	0.220	0.000
11	0	0	0	NA	0.220	0.000
12	0	1	1	1.000	0.220	0.220
13	0	0	0	NA	0.220	0.000
14	0	0	0	NA	0.220	0.000
15	0	0	0	NA	0.220	0.000
16	7	0	7	0.000	0.220	1.542
Total	27	6	33	—	—	10.402

7.3 Estimating Prior Distributions

Adjusted n_k values for the “other” CCF events were obtained for each group size by adding the estimated number of complete CCF events to the final n_k value for the partial CCF events. Table 7-4 shows the adjusted n_k results, as well as the n_I and n_t results, of the “other” CCF data for group sizes 2–16. The calculated MLEs (i.e., alpha factor mean values) for each group size are given in Table 7-5.

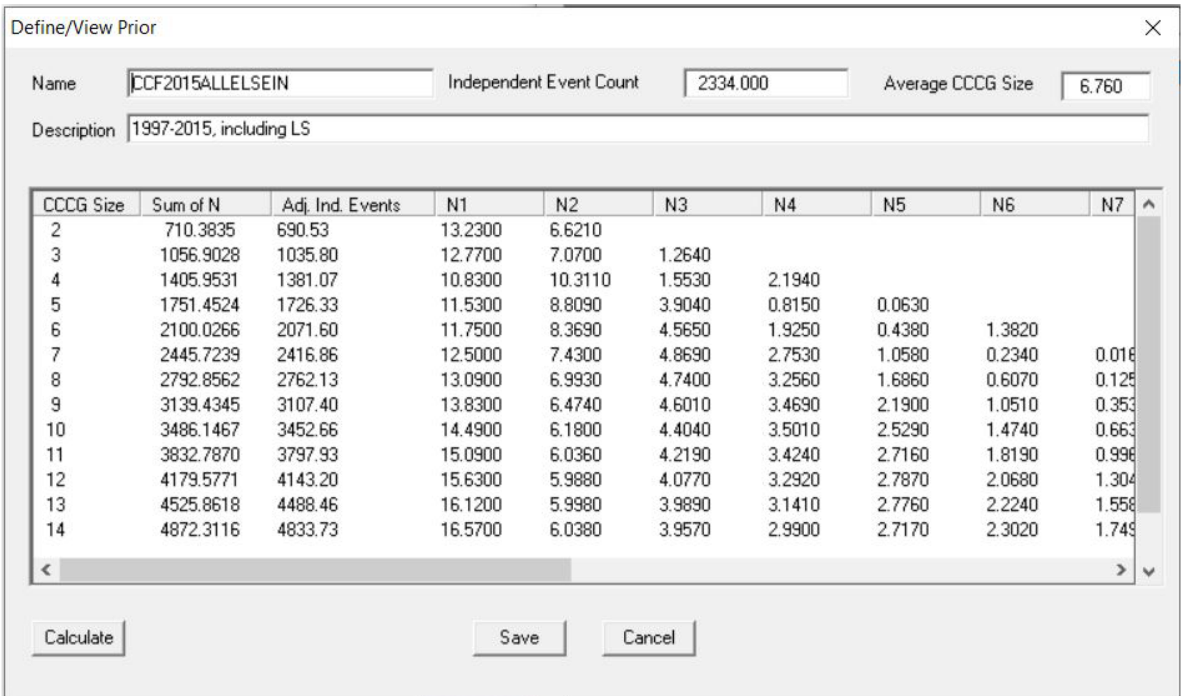
Adjusted n_k and n_I values were input to the computer code CalcPrior to estimate the industry-wide prior distributions with parameters α and β. Figure 7-1 shows the code’s needed input for calculating the prior distributions. Figure 7-2 shows the CalcPrior results for the prior distribution parameters, which were then output to Table 7-6.

Table 7-4. Adjusted *n_k* values for all CCF events (other).

Group Size	n_t	n_I	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	710.63	690.78	13.23	6.621	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	1057.27	1036.17	12.77	7.070	1.264	—	—	—	—	—	—	—	—	—	—	—	—	—
4	1406.45	1381.56	10.83	10.311	1.553	2.194	—	—	—	—	—	—	—	—	—	—	—	—
5	1752.07	1726.95	11.53	8.809	3.904	0.815	0.063	—	—	—	—	—	—	—	—	—	—	—
6	2100.77	2072.34	11.75	8.369	4.565	1.925	0.438	1.382	—	—	—	—	—	—	—	—	—	—
7	2446.59	2417.73	12.50	7.430	4.869	2.753	1.058	0.234	0.016	—	—	—	—	—	—	—	—	—
8	2793.85	2763.12	13.09	6.993	4.740	3.256	1.686	0.607	0.125	0.229	—	—	—	—	—	—	—	—
9	3140.55	3108.51	13.83	6.474	4.601	3.469	2.190	1.051	0.353	0.066	0.004	—	—	—	—	—	—	—
10	3487.38	3453.90	14.49	6.180	4.404	3.501	2.529	1.474	0.663	0.206	0.035	0.0020	—	—	—	—	—	—
11	3834.15	3799.29	15.09	6.036	4.219	3.424	2.716	1.819	0.996	0.419	0.119	0.0190	0.0010	—	—	—	—	—
12	4181.06	4144.68	15.63	5.988	4.077	3.292	2.787	2.068	1.304	0.674	0.263	0.0680	0.0100	0.2208	—	—	—	—
13	4527.47	4490.07	16.12	5.998	3.989	3.141	2.776	2.224	1.558	0.934	0.453	0.1630	0.0390	0.0051	0.0002	—	—	—
14	4874.04	4835.46	16.57	6.038	3.957	2.990	2.717	2.302	1.749	1.169	0.665	0.3020	0.1000	0.0220	0.0027	0.0001	—	—
15	5220.57	5180.85	16.99	6.087	3.980	2.848	2.631	2.322	1.878	1.365	0.874	0.4700	0.1980	0.0607	0.0123	0.0014	0.0001	—
16	5568.59	5526.24	17.39	6.130	4.054	2.719	2.536	2.302	1.954	1.515	1.061	0.6490	0.3280	0.1284	0.0364	0.0068	0.0007	1.5420

Table 7-5. Calculated alpha factor mean values (other).

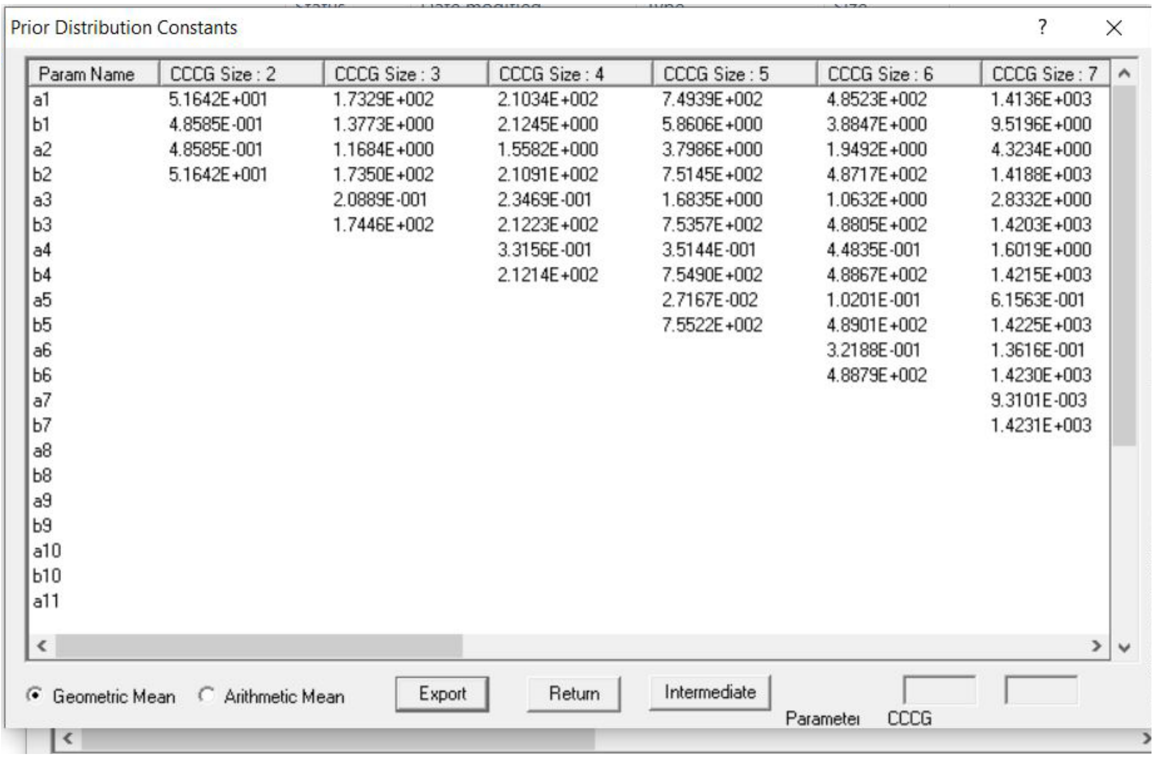
Group Size	$\boldsymbol{\alpha_1}$	$\boldsymbol{\alpha_2}$	$\boldsymbol{\alpha_3}$	$\boldsymbol{\alpha_4}$	$\boldsymbol{\alpha_5}$	$\boldsymbol{\alpha_6}$	$\boldsymbol{\alpha_7}$	$\boldsymbol{\alpha_8}$	$\boldsymbol{\alpha_9}$	$\boldsymbol{\alpha_{10}}$	$\boldsymbol{\alpha_{11}}$	$\boldsymbol{\alpha_{12}}$	$\boldsymbol{\alpha_{13}}$	$\boldsymbol{\alpha_{14}}$	$\boldsymbol{\alpha_{15}}$	$\boldsymbol{\alpha_{16}}$
2	0.9907	9.317E-03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9921	6.687E-03	1.196E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9900	7.331E-03	1.104E-03	1.560E-03	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9922	5.028E-03	2.228E-03	4.652E-04	3.596E-05	—	—	—	—	—	—	—	—	—	—	—
6	0.9921	3.984E-03	2.173E-03	9.163E-04	2.085E-04	6.579E-04	—	—	—	—	—	—	—	—	—	—
7	0.9933	3.037E-03	1.990E-03	1.125E-03	4.324E-04	9.564E-05	6.540E-06	—	—	—	—	—	—	—	—	—
8	0.9937	2.503E-03	1.697E-03	1.165E-03	6.035E-04	2.173E-04	4.474E-05	8.197E-05	—	—	—	—	—	—	—	—
9	0.9942	2.061E-03	1.465E-03	1.105E-03	6.973E-04	3.347E-04	1.124E-04	2.102E-05	1.274E-06	—	—	—	—	—	—	—
10	0.9946	1.772E-03	1.263E-03	1.004E-03	7.252E-04	4.227E-04	1.901E-04	5.907E-05	1.004E-05	5.735E-07	—	—	—	—	—	—
11	0.9948	1.574E-03	1.100E-03	8.930E-04	7.084E-04	4.744E-04	2.598E-04	1.093E-04	3.104E-05	4.955E-06	2.608E-07	—	—	—	—	—
12	0.9950	1.432E-03	9.751E-04	7.874E-04	6.666E-04	4.946E-04	3.119E-04	1.612E-04	6.290E-05	1.626E-05	2.392E-06	5.281E-05	—	—	—	—
13	0.9953	1.325E-03	8.811E-04	6.938E-04	6.131E-04	4.912E-04	3.441E-04	2.063E-04	1.001E-04	3.600E-05	8.614E-06	1.126E-06	4.417E-08	—	—	—
14	0.9955	1.239E-03	8.119E-04	6.135E-04	5.574E-04	4.723E-04	3.588E-04	2.398E-04	1.364E-04	6.196E-05	2.052E-05	4.514E-06	5.540E-07	2.052E-08	—	—
15	0.9956	1.166E-03	7.624E-04	5.455E-04	5.040E-04	4.448E-04	3.597E-04	2.615E-04	1.674E-04	9.003E-05	3.793E-05	1.163E-05	2.356E-06	2.682E-07	1.916E-08	—
16	0.9955	1.101E-03	7.280E-04	4.883E-04	4.554E-04	4.134E-04	3.509E-04	2.721E-04	1.905E-04	1.165E-04	5.890E-05	2.306E-05	6.537E-06	1.221E-06	1.257E-07	2.769E-04



Name: CCF2015ALLELSEIN
Independent Event Count: 2334.000
Average CCCG Size: 6.760
Description: 1997-2015, including LS

CCCG Size	Sum of N	Adj. Ind. Events	N1	N2	N3	N4	N5	N6	N7
2	710.3835	690.53	13.2300	6.6210					
3	1056.9028	1035.80	12.7700	7.0700	1.2640				
4	1405.9531	1381.07	10.8300	10.3110	1.5530	2.1940			
5	1751.4524	1726.33	11.5300	8.8090	3.9040	0.8150	0.0630		
6	2100.0266	2071.60	11.7500	8.3690	4.5650	1.9250	0.4380	1.3820	
7	2445.7239	2416.86	12.5000	7.4300	4.8690	2.7530	1.0580	0.2340	0.01
8	2792.8562	2762.13	13.0900	6.9930	4.7400	3.2560	1.6860	0.6070	0.12
9	3139.4345	3107.40	13.8300	6.4740	4.6010	3.4690	2.1900	1.0510	0.35
10	3486.1467	3452.66	14.4900	6.1800	4.4040	3.5010	2.5290	1.4740	0.66
11	3832.7870	3797.93	15.0900	6.0360	4.2190	3.4240	2.7160	1.8190	0.99
12	4179.5771	4143.20	15.6300	5.9880	4.0770	3.2920	2.7870	2.0680	1.30
13	4525.8618	4488.46	16.1200	5.9980	3.9890	3.1410	2.7760	2.2240	1.55
14	4872.3116	4833.73	16.5700	6.0380	3.9570	2.9900	2.7170	2.3020	1.74

Figure 7-1. Input to the CalcPrior code for estimating CCF prior distributions (other).



Param Name	CCCG Size : 2	CCCG Size : 3	CCCG Size : 4	CCCG Size : 5	CCCG Size : 6	CCCG Size : 7
a1	5.1642E+001	1.7329E+002	2.1034E+002	7.4939E+002	4.8523E+002	1.4136E+003
b1	4.8585E-001	1.3773E+000	2.1245E+000	5.8606E+000	3.8847E+000	9.5196E+000
a2	4.8585E-001	1.1684E+000	1.5582E+000	3.7986E+000	1.9492E+000	4.3234E+000
b2	5.1642E+001	1.7350E+002	2.1091E+002	7.5145E+002	4.8717E+002	1.4188E+003
a3		2.0889E-001	2.3469E-001	1.6835E+000	1.0632E+000	2.8332E+000
b3		1.7446E+002	2.1223E+002	7.5357E+002	4.8805E+002	1.4203E+003
a4			3.3156E-001	3.5144E-001	4.4835E-001	1.6019E+000
b4			2.1214E+002	7.5490E+002	4.8867E+002	1.4215E+003
a5				2.7167E-002	1.0201E-001	6.1563E-001
b5				7.5522E+002	4.8901E+002	1.4225E+003
a6					3.2188E-001	1.3616E-001
b6					4.8879E+002	1.4230E+003
a7						9.3101E-003
b7						1.4231E+003
a8						
b8						
a9						
b9						
a10						
b10						
a11						

● Geometric Mean ○ Arithmetic Mean

Figure 7-2. CCF prior distribution parameters calculated by the CalcPrior code (other).

Table 7-6. Estimated industry-wide alpha factor prior distributions (other).

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	5.16E+01	4.86E-01	4.86E-01	5.16E+01	—	—	—	—	—	—	—	—	—	—	—	—
3	1.73E+02	1.38E+00	1.17E+00	1.74E+02	2.09E-01	1.74E+02	—	—	—	—	—	—	—	—	—	—
4	2.10E+02	2.12E+00	1.56E+00	2.11E+02	2.35E-01	2.12E+02	3.32E-01	2.12E+02	—	—	—	—	—	—	—	—
5	7.49E+02	5.86E+00	3.80E+00	7.51E+02	1.68E+00	7.54E+02	3.51E-01	7.55E+02	2.72E-02	7.55E+02	—	—	—	—	—	—
6	4.85E+02	3.88E+00	1.95E+00	4.87E+02	1.06E+00	4.88E+02	4.48E-01	4.89E+02	1.02E-01	4.89E+02	3.22E-01	4.89E+02	—	—	—	—
7	1.41E+03	9.52E+00	4.32E+00	1.42E+03	2.83E+00	1.42E+03	1.60E+00	1.42E+03	6.16E-01	1.42E+03	1.36E-01	1.42E+03	9.31E-03	1.42E+03	—	—
8	1.17E+03	7.46E+00	2.96E+00	1.18E+03	2.01E+00	1.18E+03	1.38E+00	1.18E+03	7.13E-01	1.18E+03	2.57E-01	1.18E+03	5.29E-02	1.18E+03	9.69E-02	1.18E+03
9	2.51E+03	1.46E+01	5.20E+00	2.52E+03	3.70E+00	2.52E+03	2.79E+00	2.52E+03	1.76E+00	2.52E+03	8.44E-01	2.52E+03	2.84E-01	2.52E+03	5.30E-02	2.52E+03
10	3.25E+03	1.78E+01	5.80E+00	3.27E+03	4.13E+00	3.27E+03	3.29E+00	3.27E+03	2.37E+00	3.27E+03	1.38E+00	3.27E+03	6.22E-01	3.27E+03	1.93E-01	3.27E+03
11	4.16E+03	2.15E+01	6.58E+00	4.17E+03	4.60E+00	4.17E+03	3.73E+00	4.17E+03	2.96E+00	4.17E+03	1.98E+00	4.18E+03	1.09E+00	4.18E+03	4.57E-01	4.18E+03
12	3.02E+03	1.51E+01	4.35E+00	3.03E+03	2.96E+00	3.04E+03	2.39E+00	3.04E+03	2.03E+00	3.04E+03	1.50E+00	3.04E+03	9.48E-01	3.04E+03	4.90E-01	3.04E+03
13	6.72E+03	3.17E+01	8.95E+00	6.74E+03	5.95E+00	6.75E+03	4.69E+00	6.75E+03	4.14E+00	6.75E+03	3.32E+00	6.75E+03	2.32E+00	6.75E+03	1.39E+00	6.75E+03
14	8.32E+03	3.77E+01	1.04E+01	8.34E+03	6.78E+00	8.35E+03	5.13E+00	8.35E+03	4.66E+00	8.35E+03	3.95E+00	8.35E+03	3.00E+00	8.35E+03	2.00E+00	8.35E+03
15	9.73E+03	4.26E+01	1.14E+01	9.77E+03	7.46E+00	9.77E+03	5.34E+00	9.77E+03	4.93E+00	9.77E+03	4.35E+00	9.77E+03	3.52E+00	9.77E+03	2.56E+00	9.77E+03
16	6.00E+03	2.70E+01	6.64E+00	6.02E+03	4.39E+00	6.03E+03	2.95E+00	6.03E+03	2.75E+00	6.03E+03	2.49E+00	6.03E+03	2.12E+00	6.03E+03	1.64E+00	6.03E+03

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	3.21E-03	2.52E+03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	3.29E-02	3.27E+03	1.88E-03	3.27E+03	—	—	—	—	—	—	—	—	—	—	—	—
11	1.30E-01	4.18E+03	2.07E-02	4.18E+03	1.09E-03	4.18E+03	—	—	—	—	—	—	—	—	—	—
12	1.91E-01	3.04E+03	4.94E-02	3.04E+03	7.27E-03	3.04E+03	1.60E-01	3.04E+03	—	—	—	—	—	—	—	—
13	6.76E-01	6.75E+03	2.43E-01	6.75E+03	5.82E-02	6.75E+03	7.61E-03	6.75E+03	2.98E-04	6.75E+03	—	—	—	—	—	—
14	1.14E+00	8.35E+03	5.18E-01	8.35E+03	1.71E-01	8.35E+03	3.77E-02	8.35E+03	4.63E-03	8.35E+03	1.71E-04	8.35E+03	—	—	—	—
15	1.64E+00	9.78E+03	8.80E-01	9.78E+03	3.71E-01	9.78E+03	1.14E-01	9.78E+03	2.30E-02	9.78E+03	2.62E-03	9.78E+03	1.87E-04	9.78E+03	—	—
16	1.15E+00	6.03E+03	7.03E-01	6.03E+03	3.55E-01	6.03E+03	1.39E-01	6.03E+03	3.94E-02	6.03E+03	7.37E-03	6.03E+03	7.58E-04	6.03E+03	1.67E+00	6.03E+03

7.4 Sensitivity Study

This section presents the sensitivity study results for “other” components when distinguishing the **one “other” lethal shock event** from the non-lethal-shock-but-complete-CCF events in Table 7-7 and adding that lethal shock event to the final n_k values of the corresponding group size in Table 7-8. Thus, in Table 7-7, for the group size of 2, the number of complete CCF events with non-lethal shocks is three instead of four, as there is one lethal shock event. That one lethal shock event is added to the n_m (for the group size of m) values in Table 7-2, along with the new estimated number of complete CCF events (with non-lethal shocks only) in Table 7-7. Now, in Table 7-8, the adjusted n_3 for the group size of 3 is 2.264 instead of 1.264, and the adjusted n_{16} for the group size of 16 is 2.7528 instead of 1.5420, which is the value given in Table 7-4.

Figure 7-3 and Figure 7-4 show the input to and output from the CalcPrior code, respectively. Table 7-9 presents the alpha factor mean values, and Table 7-10 provides the prior distribution parameters for the sensitivity study.

In comparing the values in Table 7-9 to those in Table 7-5, we find that the estimated alpha factor mean values for α_m in the group size of m would be increased when distinguishing lethal shocks from non-lethal shocks in the analysis (e.g., α_3 in the group size of 3 is increased from 1.20E-3 to 2.14E-3, α_4 in the group size of 4 is increased from 1.56E-3 to 2.39E-3, α_8 in the group size of 8 is increased from 8.20E-5 to 4.51E-4, and α_{16} in the group size of 16 is increased from 2.77E-4 to 4.94E-4).

Table 7-7. CCF data with curve-fitted complete CCF events (other, non-lethal shocks only).

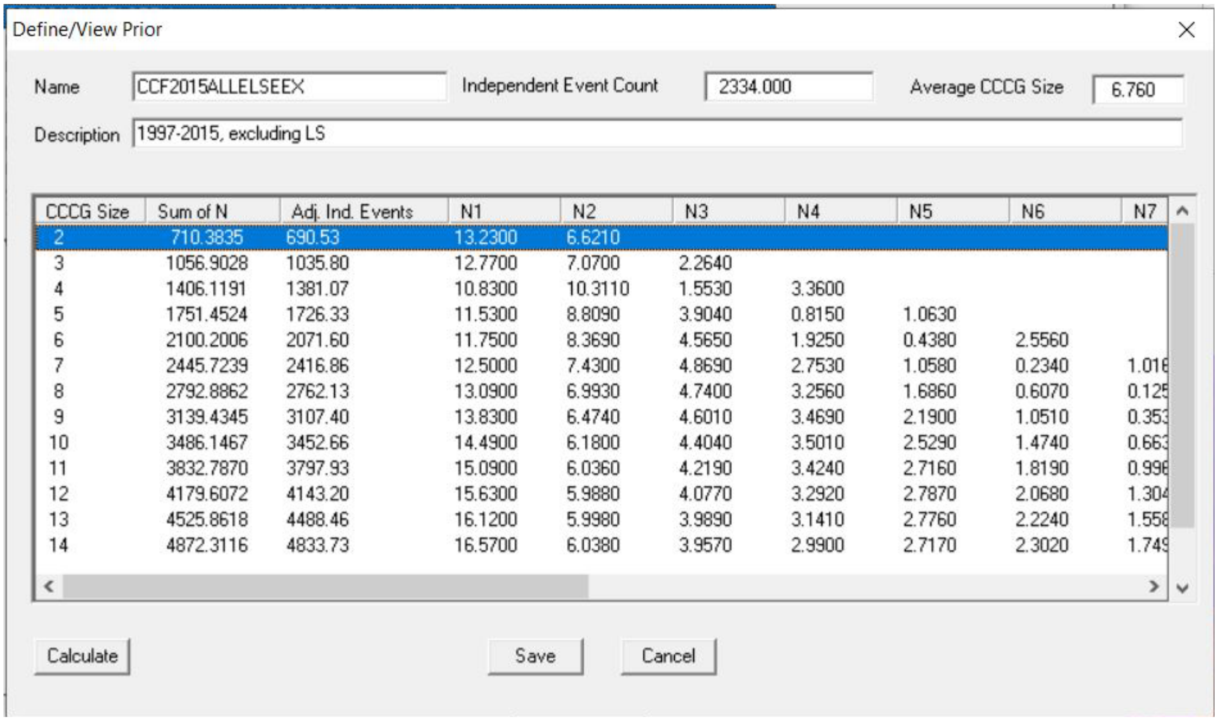
Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events	Prob. of Complete CCF Event - Data	Prob. of Complete CCF Event - Curve Fitting	Estimated No. Complete CCF Events
2	3	3	6	0.500	0.500	3.000
3	2	1	3	0.333	0.333	1.000
4	8	0	8	0000	0.279	2.234
5	0	0	0	NA	0.261	0.000
6	6	0	6	0.000	0.254	1.525
7	0	0	0	NA	0.252	0.000
8	1	0	1	0.000	0.251	0.251
9	0	0	0	NA	0.251	0.000
10	0	0	0	NA	0.250	0.000
11	0	0	0	NA	0.250	0.000
12	0	1	1	1.000	0.250	0.250
13	0	0	0	NA	0.250	0.000
14	0	0	0	NA	0.250	0.000
15	0	0	0	NA	0.250	0.000
16	7	0	7	0.000	0.250	1.753
Total	27	5	32	—	—	10.013

Table 7-8. Adjusted n_k values for all CCF events (other, distinguishing lethal shocks from non-lethal shocks).

Group Size	n_t	n_I	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8	n_9	n_{10}	n_{11}	n_{12}	n_{13}	n_{14}	n_{15}	n_{16}
2	710.63	690.78	13.23	6.621	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	1058.27	1036.17	12.77	7.070	2.264	—	—	—	—	—	—	—	—	—	—	—	—	—
4	1407.61	1381.56	10.83	10.311	1.553	3.360	—	—	—	—	—	—	—	—	—	—	—	—
5	1753.07	1726.95	11.53	8.809	3.904	0.815	1.063	—	—	—	—	—	—	—	—	—	—	—
6	2101.94	2072.34	11.75	8.369	4.565	1.925	0.438	2.556	—	—	—	—	—	—	—	—	—	—
7	2447.59	2417.73	12.50	7.430	4.869	2.753	1.058	0.234	1.016	—	—	—	—	—	—	—	—	—
8	2794.88	2763.12	13.09	6.993	4.740	3.256	1.686	0.607	0.125	1.259	—	—	—	—	—	—	—	—
9	3141.55	3108.51	13.83	6.474	4.601	3.469	2.190	1.051	0.353	0.066	1.004	—	—	—	—	—	—	—
10	3488.38	3453.90	14.49	6.180	4.404	3.501	2.529	1.474	0.663	0.206	0.035	1.0020	—	—	—	—	—	—
11	3835.15	3799.29	15.09	6.036	4.219	3.424	2.716	1.819	0.996	0.419	0.119	0.0190	1.0010	—	—	—	—	—
12	4182.09	4144.68	15.63	5.988	4.077	3.292	2.787	2.068	1.304	0.674	0.263	0.0680	0.0100	1.2509	—	—	—	—
13	4528.47	4490.07	16.12	5.998	3.989	3.141	2.776	2.224	1.558	0.934	0.453	0.1630	0.0390	0.0051	1.0002	—	—	—
14	4875.04	4835.46	16.57	6.038	3.957	2.990	2.717	2.302	1.749	1.169	0.665	0.3020	0.1000	0.0220	0.0027	1.0001	—	—
15	5221.57	5180.85	16.99	6.087	3.980	2.848	2.631	2.322	1.878	1.365	0.874	0.4700	0.1980	0.0607	0.0123	0.0014	1.0001	—
16	5569.80	5526.24	17.39	6.130	4.054	2.719	2.536	2.302	1.954	1.515	1.061	0.6490	0.3280	0.1284	0.0364	0.0068	0.0007	2.7528

Table 7-9. Calculated alpha factor mean values (other, distinguishing lethal shocks from non-lethal shocks).

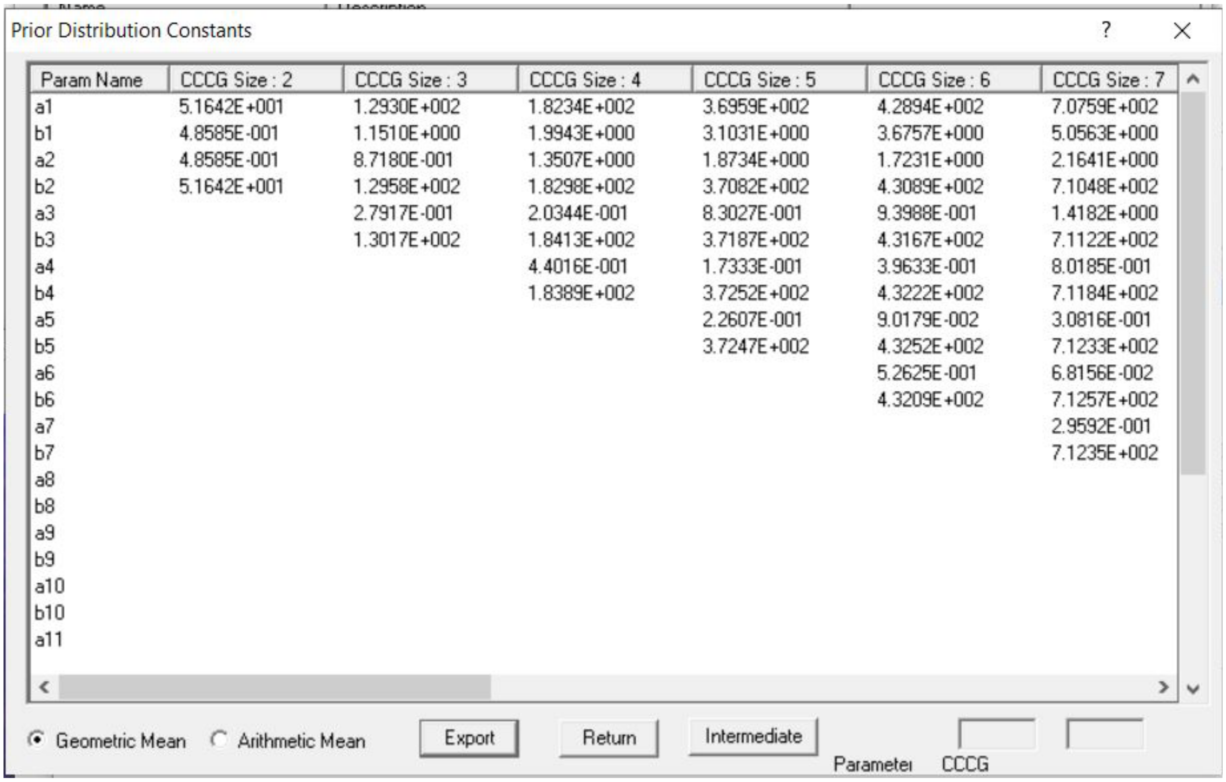
Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9907	9.317E-03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9912	6.681E-03	2.139E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9892	7.325E-03	1.103E-03	2.387E-03	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9917	5.025E-03	2.227E-03	4.649E-04	6.064E-04	—	—	—	—	—	—	—	—	—	—	—
6	0.9915	3.982E-03	2.172E-03	9.158E-04	2.084E-04	1.216E-03	—	—	—	—	—	—	—	—	—	—
7	0.9929	3.036E-03	1.989E-03	1.125E-03	4.323E-04	9.560E-05	4.151E-04	—	—	—	—	—	—	—	—	—
8	0.9933	2.502E-03	1.696E-03	1.165E-03	6.032E-04	2.172E-04	4.472E-05	4.505E-04	—	—	—	—	—	—	—	—
9	0.9939	2.061E-03	1.465E-03	1.104E-03	6.971E-04	3.345E-04	1.124E-04	2.101E-05	3.196E-04	—	—	—	—	—	—	—
10	0.9943	1.772E-03	1.262E-03	1.004E-03	7.250E-04	4.225E-04	1.901E-04	5.905E-05	1.003E-05	2.872E-04	—	—	—	—	—	—
11	0.9946	1.574E-03	1.100E-03	8.928E-04	7.082E-04	4.743E-04	2.597E-04	1.093E-04	3.103E-05	4.954E-06	2.610E-04	—	—	—	—	—
12	0.9948	1.432E-03	9.749E-04	7.872E-04	6.664E-04	4.945E-04	3.118E-04	1.612E-04	6.289E-05	1.626E-05	2.391E-06	2.991E-04	—	—	—	—
13	0.9951	1.325E-03	8.809E-04	6.936E-04	6.130E-04	4.911E-04	3.440E-04	2.063E-04	1.000E-04	3.599E-05	8.612E-06	1.126E-06	2.209E-04	—	—	—
14	0.9953	1.239E-03	8.117E-04	6.133E-04	5.573E-04	4.722E-04	3.588E-04	2.398E-04	1.364E-04	6.195E-05	2.051E-05	4.513E-06	5.538E-07	2.051E-04	—	—
15	0.9955	1.166E-03	7.622E-04	5.454E-04	5.039E-04	4.447E-04	3.597E-04	2.614E-04	1.674E-04	9.001E-05	3.792E-05	1.162E-05	2.356E-06	2.681E-07	1.915E-04	—
16	0.9953	1.101E-03	7.279E-04	4.882E-04	4.553E-04	4.133E-04	3.508E-04	2.720E-04	1.905E-04	1.165E-04	5.889E-05	2.305E-05	6.535E-06	1.221E-06	1.257E-07	4.942E-04



Name: CCF2015ALLELSEEX
Independent Event Count: 2334.000
Average CCCG Size: 6.760
Description: 1997-2015, excluding LS

CCCG Size	Sum of N	Adj. Ind. Events	N1	N2	N3	N4	N5	N6	N7
2	710.3835	690.53	13.2300	6.6210					
3	1056.9028	1035.80	12.7700	7.0700	2.2640				
4	1406.1191	1381.07	10.8300	10.3110	1.5530	3.3600			
5	1751.4524	1726.33	11.5300	8.8090	3.9040	0.8150	1.0630		
6	2100.2006	2071.60	11.7500	8.3690	4.5650	1.9250	0.4380	2.5560	
7	2445.7239	2416.86	12.5000	7.4300	4.8690	2.7530	1.0580	0.2340	1.01
8	2792.8862	2762.13	13.0900	6.9930	4.7400	3.2560	1.6860	0.6070	0.12
9	3139.4345	3107.40	13.8300	6.4740	4.6010	3.4690	2.1900	1.0510	0.35
10	3486.1467	3452.66	14.4900	6.1800	4.4040	3.5010	2.5290	1.4740	0.66
11	3832.7870	3797.93	15.0900	6.0360	4.2190	3.4240	2.7160	1.8190	0.99
12	4179.6072	4143.20	15.6300	5.9880	4.0770	3.2920	2.7870	2.0680	1.30
13	4525.8618	4488.46	16.1200	5.9980	3.9890	3.1410	2.7760	2.2240	1.55
14	4872.3116	4833.73	16.5700	6.0380	3.9570	2.9900	2.7170	2.3020	1.74

Figure 7-3. Input to the CalcPrior code for estimating CCF prior distributions (other, distinguishing lethal shocks from non-lethal shocks).



Param Name	CCCG Size : 2	CCCG Size : 3	CCCG Size : 4	CCCG Size : 5	CCCG Size : 6	CCCG Size : 7
a1	5.1642E+001	1.2930E+002	1.8234E+002	3.6959E+002	4.2894E+002	7.0759E+002
b1	4.8585E-001	1.1510E+000	1.9943E+000	3.1031E+000	3.6757E+000	5.0563E+000
a2	4.8585E-001	8.7180E-001	1.3507E+000	1.8734E+000	1.7231E+000	2.1641E+000
b2	5.1642E+001	1.2958E+002	1.8298E+002	3.7082E+002	4.3089E+002	7.1048E+002
a3		2.7917E-001	2.0344E-001	8.3027E-001	9.3988E-001	1.4182E+000
b3		1.3017E+002	1.8413E+002	3.7187E+002	4.3167E+002	7.1122E+002
a4			4.4016E-001	1.7333E-001	3.9633E-001	8.0185E-001
b4			1.8389E+002	3.7252E+002	4.3222E+002	7.1184E+002
a5				2.2607E-001	9.0179E-002	3.0816E-001
b5				3.7247E+002	4.3252E+002	7.1233E+002
a6					5.2625E-001	6.8156E-002
b6					4.3209E+002	7.1257E+002
a7						2.9592E-001
b7						7.1235E+002
a8						
b8						
a9						
b9						
a10						
b10						
a11						

● Geometric Mean ○ Arithmetic Mean

Figure 7-4. CCF prior distribution parameters calculated by the CalcPrior code (other, distinguishing lethal shocks from non-lethal shocks).

Table 7-10. Estimated industry-wide alpha factor prior distributions (other, distinguishing lethal shocks from non-lethal shocks).

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	5.16E+01	4.86E-01	4.86E-01	5.16E+01	—	—	—	—	—	—	—	—	—	—	—	—
3	1.29E+02	1.15E+00	8.72E-01	1.30E+02	2.79E-01	1.30E+02	—	—	—	—	—	—	—	—	—	—
4	1.82E+02	1.99E+00	1.35E+00	1.83E+02	2.03E-01	1.84E+02	4.40E-01	1.84E+02	—	—	—	—	—	—	—	—
5	3.70E+02	3.10E+00	1.87E+00	3.71E+02	8.30E-01	3.72E+02	1.73E-01	3.73E+02	2.26E-01	3.72E+02	—	—	—	—	—	—
6	4.29E+02	3.68E+00	1.72E+00	4.31E+02	9.40E-01	4.32E+02	3.96E-01	4.32E+02	9.02E-02	4.33E+02	5.26E-01	4.32E+02	—	—	—	—
7	7.08E+02	5.06E+00	2.16E+00	7.10E+02	1.42E+00	7.11E+02	8.02E-01	7.12E+02	3.08E-01	7.12E+02	6.82E-02	7.13E+02	2.96E-01	7.12E+02	—	—
8	9.20E+02	6.19E+00	2.32E+00	9.24E+02	1.57E+00	9.25E+02	1.08E+00	9.25E+02	5.59E-01	9.26E+02	2.01E-01	9.26E+02	4.14E-02	9.26E+02	4.17E-01	9.26E+02
9	1.26E+03	7.73E+00	2.61E+00	1.26E+03	1.85E+00	1.26E+03	1.40E+00	1.26E+03	8.82E-01	1.26E+03	4.23E-01	1.26E+03	1.42E-01	1.26E+03	2.66E-02	1.26E+03
10	1.63E+03	9.41E+00	2.91E+00	1.64E+03	2.07E+00	1.64E+03	1.65E+00	1.64E+03	1.19E+00	1.64E+03	6.93E-01	1.64E+03	3.12E-01	1.64E+03	9.69E-02	1.64E+03
11	2.08E+03	1.13E+01	3.30E+00	2.09E+03	2.30E+00	2.09E+03	1.87E+00	2.09E+03	1.48E+00	2.09E+03	9.93E-01	2.09E+03	5.44E-01	2.09E+03	2.29E-01	2.09E+03
12	2.58E+03	1.35E+01	3.72E+00	2.59E+03	2.53E+00	2.59E+03	2.04E+00	2.59E+03	1.73E+00	2.59E+03	1.28E+00	2.59E+03	8.10E-01	2.59E+03	4.18E-01	2.59E+03
13	3.30E+03	1.63E+01	4.40E+00	3.32E+03	2.93E+00	3.32E+03	2.30E+00	3.32E+03	2.04E+00	3.32E+03	1.63E+00	3.32E+03	1.14E+00	3.32E+03	6.85E-01	3.32E+03
14	4.09E+03	1.94E+01	5.10E+00	4.11E+03	3.34E+00	4.11E+03	2.52E+00	4.11E+03	2.29E+00	4.11E+03	1.94E+00	4.11E+03	1.48E+00	4.11E+03	9.87E-01	4.11E+03
15	9.73E+03	4.26E+01	1.14E+01	9.77E+03	7.46E+00	9.77E+03	5.34E+00	9.77E+03	4.93E+00	9.77E+03	4.35E+00	9.77E+03	3.52E+00	9.77E+03	2.56E+00	9.77E+03
16	5.95E+03	2.70E+01	6.59E+00	5.97E+03	4.35E+00	5.98E+03	2.92E+00	5.98E+03	2.72E+00	5.98E+03	2.47E+00	5.98E+03	2.10E+00	5.98E+03	1.63E+00	5.98E+03

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	4.04E-01	1.26E+03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	1.65E-02	1.64E+03	4.71E-01	1.64E+03	—	—	—	—	—	—	—	—	—	—	—	—
11	6.50E-02	2.09E+03	1.04E-02	2.09E+03	5.47E-01	2.09E+03	—	—	—	—	—	—	—	—	—	—
12	1.63E-01	2.60E+03	4.22E-02	2.60E+03	6.21E-03	2.60E+03	7.77E-01	2.59E+03	—	—	—	—	—	—	—	—
13	3.32E-01	3.32E+03	1.20E-01	3.32E+03	2.86E-02	3.32E+03	3.74E-03	3.32E+03	7.34E-01	3.32E+03	—	—	—	—	—	—
14	5.61E-01	4.11E+03	2.55E-01	4.11E+03	8.44E-02	4.11E+03	1.86E-02	4.11E+03	2.28E-03	4.11E+03	8.44E-01	4.11E+03	—	—	—	—
15	1.64E+00	9.78E+03	8.80E-01	9.78E+03	3.71E-01	9.78E+03	1.14E-01	9.78E+03	2.30E-02	9.78E+03	2.62E-03	9.78E+03	1.87E-04	9.78E+03	—	—
16	1.14E+00	5.98E+03	6.97E-01	5.98E+03	3.52E-01	5.98E+03	1.38E-01	5.98E+03	3.91E-02	5.98E+03	7.30E-03	5.98E+03	7.52E-04	5.98E+03	1.88E+00	5.98E+03

8. ESTIMATING ALPHA FACTORS FOR SELECTED CCF TEMPLATES, USING COMPONENT-SPECIFIC PRIORS

This section selects several representative CCF templates, estimates CCF parameters for them by using component-specific priors, and compares the results against the 2020 CCF parameter estimates [10], which used the 2015 generic priors.

8.1 Selected CCF Templates

Nine representative CCF templates spanning five component categories (Table 8-1) were selected for this study.

Table 8-1. Selected CCF templates.

Component Category	Failure Mode	Reference for Generic Estimates
Pump	Pooled motor-driven pumps fail to start: ALL-MDP-FS	Section 2.1.1.1 [10]
Pump	Auxiliary feedwater motor-driven pumps fail to start: AFW-MDP-FS	Section 2.1.6.1 [10]
Valve	Pooled motor-operated valves fail to open/close: ALL-MOV-FTOC	Section 2.3.1.1 [10]
Valve	Auxiliary feedwater air-operated valves fail to open/close: AFW-AOV-FTOC	Section 2.4.2.1 [10]
Valve	Pooled safety valves (direct acting) fail to open: ALL-SVV-CC	Section 2.8.1.1 [10]
Strainer	Pooled traveling screens plug: ALL-TSA-PG	Section 2.6.1 [10]
Generator	Emergency diesel generators fail to start: EPS-EDG-FS	Section 2.11.1.1 [10]
Generator	Emergency diesel generators fail to run: EPS-EDG-FR	Section 2.11.1.3 [10]
Other	DC power batteries fail to operate: DCP-BAT-LP	Section 2.14.1.1 [10]

8.2 Estimating Alpha Factor Posteriors by Using Component-Specific Priors

For alpha factors, posterior distribution shape parameters (i.e., *a* and *b* for Beta distributions) can be manually calculated from the prior distribution shape parameters and adjusted n_I and n_k values by using Eqs. (5) to (8) (refer to Appendix B of [12]). Posterior mean values for alpha factors can then be calculated using Eq. (9).

$$a_1^{posterior} = a_1^{prior} + n_1 + n_I \tag{5}$$

$$b_1^{posterior} = b_1^{prior} + n_t - n_1 - n_I \tag{6}$$

$$a_k^{posterior} = a_k^{prior} + n_k \tag{7}$$

$$b_k^{posterior} = b_k^{prior} + n_t - n_k \tag{8}$$

$$\alpha_{mean}^{posterior} = a^{posterior} / (a^{posterior} + b^{posterior}) \tag{9}$$

The adjusted n_I and n_k values for each CCF template can be obtained from the Avg. Impact Vector tables corresponding to those CCF templates in the 2020 CCF parameter update [10] (e.g., page 20 shows the Avg. Impact Vector table for CCF template ALL-MDP-FS). Table 8-2 presents a copy of the table for group sizes 2, 3, and 4 (with rounded-off values). Using the 2015 generic priors (see Section 3.1.3 of [10]), the above equations can be used to manually calculate the CCF posterior distribution parameters for ALL-MDP-FS. This would produce the same results as seen in page 18 of [10].

Table 8-2. Average impact vector values for ALL-MDP-FS, group sizes 2–4 [10].

Average Impact Vector	CCCG = 2	CCCG = 3	CCCG = 4
Adjusted Independent Failure (n_I)	143.12	214.67	286.23
N1 (n_1)	1.80	2.02	2.04
N2 (n_2)	1.35	0.68	0.98
N3 (n_3)	—	1.13	0.75
N4 (n_4)	—	—	0.56

Now, using the 2015 pump priors developed in Section 3.3 of this report (as shown in Table 8-3 as a recap), we can obtain a new set of CCF posterior distribution parameters (Table 8-4) and alpha factor mean values (Table 8-5) for ALL-MDP-FS.

Table 8-3. 2015 pump prior distribution parameters for group sizes 2–4 (from Table 3-6).

Group size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	42.50	0.48	0.48	42.50	—	—	—	—
3	118.00	1.26	1.02	118.00	0.24	119.00	—	—
4	187.00	2.14	1.51	188.00	0.45	189.00	0.18	189.00

Table 8-4. Posterior distribution parameters for ALL-MDP-FS, using the 2015 pump priors.

Group size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	187.42	1.83	1.83	187.42	—	—	—	—
3	334.69	3.06	1.70	335.81	1.36	336.37	—	—
4	475.27	4.43	2.49	477.58	1.20	478.81	0.74	479.00

Table 8-5. Alpha factor mean values for ALL-MDP-FS, using the 2015 pump priors.

Group size	α_1	α_2	α_3	α_4
2	9.90E-01	9.69E-03	—	—
3	9.91E-01	5.03E-03	4.04E-03	—
4	9.91E-01	5.19E-03	2.49E-03	1.55E-03

The following tables (Table 8-6 through Table 8-14) provide the estimated alpha factor posterior distributions for the selected CCF templates, group sizes 2–4, using the component-specific CCF priors developed in previous sections of this report.

Table 8-6. Estimated alpha factor posterior distributions for ALL-MDP-FS, using the 2015 pump priors.

Group Size	Posterior Mean Values						Posterior Distribution Shape Factors					
	α_1	α_2	α_3	α_4	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	9.90E-01	9.69E-03	—	—	187.42	1.83	1.83	187.42	—	—	—	—
3	9.91E-01	5.03E-03	4.04E-03	—	334.69	3.06	1.70	335.81	1.36	336.37	—	—
4	9.91E-01	5.19E-03	2.49E-03	1.55E-03	475.27	4.43	2.49	477.58	1.20	478.81	0.74	479.00

Table 8-7. Estimated alpha factor posterior distributions for AFW-MDP-FS, using the 2015 pump priors.

Group Size	Posterior Mean Values						Posterior Distribution Shape Factors					
	α_1	α_2	α_3	α_4	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	9.75E-01	2.46E-02	—	—	58.83	1.48	1.48	58.83	—	—	—	—
3	9.84E-01	7.06E-03	8.55E-03	—	142.50	2.26	1.02	143.50	1.24	143.50	—	—
4	9.86E-01	6.77E-03	4.24E-03	3.05E-03	219.67	3.14	1.51	221.67	0.95	222.17	0.68	222.17

Table 8-8. Estimated alpha factor posterior distributions for ALL-MOV-FTOC, using the 2015 valve priors.

Group Size	Posterior Mean Values						Posterior Distribution Shape Factors					
	α_1	α_2	α_3	α_4	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	9.96E-01	3.68E-03	—	——	188.10	0.69	0.69	188.10	—	—	—	—
3	9.93E-01	5.71E-03	7.77E-04		297.85	1.95	1.71	298.05	0.23	299.50	—	—
4	9.91E-01	6.92E-03	1.24E-03	4.12E-04	403.90	3.49	2.82	404.60	0.51	406.90	0.17	407.30

Table 8-9. Estimated alpha factor posterior distributions for AFW-AOV-FTOC, using the 2015 valve priors.

Group Size	Posterior Mean Values						Posterior Distribution Shape Factors					
	α_1	α_2	α_3	α_4	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	9.59E-01	4.06E-02	—	—	45.90	1.94	1.94	45.90	—	—	—	—
3	9.65E-01	2.24E-02	1.21E-02	—	84.80	3.03	1.96	85.83	1.07	86.70	—	—
4	9.68E-01	1.53E-02	1.16E-02	5.13E-03	120.61	3.99	1.90	122.73	1.45	123.17	0.64	124.04

Table 8-10. Estimated alpha factor posterior distributions for ALL-SVV-CC, using the 2015 valve priors.

Group Size	Posterior Mean Values						Posterior Distribution Shape Factors					
	α_1	α_2	α_3	α_4	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	9.63E-01	3.73E-02	—	—	12.76	0.49	0.49	12.76	—	—	—	—
3	9.64E-01	2.97E-02	6.54E-03	—	35.46	1.34	1.09	35.67	0.24	36.49	—	—
4	9.61E-01	2.69E-02	9.32E-03	2.94E-03	54.90	2.23	1.54	55.63	0.53	56.62	0.17	57.05

Table 8-11. Estimated alpha factor posterior distributions for ALL-TSA-PG, using the 2015 strainer priors.

Group Size	Posterior Mean Values						Posterior Distribution Shape Factors					
	α_1	α_2	α_3	α_4	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	9.03E-01	9.68E-02	—	—	3.22	0.35	0.35	3.22	—	—	—	—
3	9.28E-01	5.07E-02	2.20E-02	—	12.30	0.96	0.67	12.50	0.29	12.90	—	—
4	9.24E-01	4.87E-02	1.73E-02	9.86E-03	20.90	1.72	1.10	21.50	0.39	22.20	0.22	22.40

Table 8-12. Estimated alpha factor posterior distributions for EPS-EDG-FS, using the 2015 generator priors.

Group Size	Posterior Mean Values						Posterior Distribution Shape Factors					
	α_1	α_2	α_3	α_4	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	9.92E-01	7.92E-03	—	—	61.10	0.49	0.49	61.10	—	—	—	—
3	9.93E-01	5.17E-03	2.16E-03	—	147.00	1.08	0.76	147.00	0.32	148.00	—	—
4	9.93E-01	4.03E-03	2.09E-03	8.05E-04	261.00	1.82	1.06	262.00	0.55	262.00	0.21	262.00

Table 8-13. Estimated alpha factor posterior distributions for EPS-EDG-FR, using the 2015 generator priors.

Group Size	Posterior Mean Values						Posterior Distribution Shape Factors					
	α_1	α_2	α_3	α_4	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	9.92E-01	7.92E-03	—	—	61.10	0.49	0.49	61.10	—	—	—	—
3	9.93E-01	5.17E-03	2.16E-03	—	147.00	1.08	0.76	147.00	0.32	148.00	—	—
4	9.93E-01	4.03E-03	2.09E-03	8.05E-04	261.00	1.82	1.06	262.00	0.55	262.00	0.21	262.00

Table 8-14. Estimated alpha factor posterior distributions for DCP-BAT-LP, using the 2015 “other” priors.

Group Size	Posterior Mean Values				Posterior Distribution Shape Factors							
	α_1	α_2	α_3	α_4	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
2	9.91E-01	9.33E-03	—	—	51.60	0.49	0.49	51.60	—	—	—	—
3	9.92E-01	6.68E-03	1.20E-03	—	173.00	1.38	1.17	174.00	0.21	174.00	—	—
4	9.90E-01	7.34E-03	1.11E-03	1.56E-03	210.00	2.12	1.56	211.00	0.24	212.00	0.33	212.00

8.3 Comparing Alpha Factor Parameters Derived from Component-Specific Priors Vs. Generic Priors

This section compares the alpha factor mean values calculated in Section 8.2 for the selected CCF templates against the values found in the 2020 CCF parameter update [10]. Table 8-15 to Table 8-19 present the comparison results for the pump, valve, strainer, generator, and "other" component types, respectively. The comparison revealed the following:

1. The CCF alpha factor mean values in the 2015 **pump** priors are about **50% lower** than those in the corresponding 2015 generic priors. Depending on the data observed in a specific CCF template, this difference in the values of the priors could have a larger or smaller impact on the posterior alpha factor mean values, e.g.:
    a. The CCF alpha factor mean values for ALL-MDP-FS based on the pump priors are 10–25% lower than those based on the generic priors.
    b. The CCF alpha factor mean values for AFW-MDP-FS based on the pump priors are 30–50% lower than those based on the generic priors.
    c. AFW-MDP-FS contains less observed data than ALL-MDP-FS, thus the posterior mean values are more significantly impacted by the priors.
2. The CCF alpha factor mean values in the 2015 **valve** priors are about **20–100% higher** than those in the corresponding 2015 generic priors. Depending on the data observed in a specific CCF template, this difference in the values of the priors could have a larger or smaller impact on the posterior alpha factor mean values, e.g.:
    a. The CCF alpha factor mean values for ALL-MOV-FTOC based on the valve priors vary from about 20% lower to 40% higher than the values based on the generic priors.
    b. The CCF alpha factor mean values for AFW-AOV-FTOC based on the valve priors are 20–40% higher than those based on the generic priors.
    c. The CCF alpha factor mean values for ALL-SVV-CC based on the valve priors are 20–100% higher than those based on the generic priors.
    d. Apparently, different observed data in the above CCF templates lead to different degrees of impacts on the posterior values calculated from the CCF priors.
3. The CCF alpha factor mean values in the 2015 **strainer** priors are about **2–4 times higher** than those in the corresponding 2015 generic priors. Depending on the data observed in a specific CCF template, this difference in the values of the priors could have a larger or smaller impact on the posterior alpha factor mean values (e.g., the CCF alpha factor mean values for ALL-TSA-PG based on the strainer priors are about 100% higher than the values based on the generic priors).
4. The CCF alpha factor mean values in the 2015 **generator** priors are about **60% lower** than those in the corresponding 2015 generic priors. Depending on the observed data in a specific CCF template, this difference in the values of the priors could have a larger or smaller impact on the posterior alpha factor mean values (e.g., the CCF alpha factor mean values for both EPS-EDG-FS and EPS-EDG-FR based on the generator priors are 20–40% lower than the values based on the generic priors).
5. The CCF alpha factor mean values in the 2015 **other** priors are about **40–75% lower** than those in the corresponding 2015 generic priors. Depending on the observed data in a specific CCF template, this difference in the values of the priors could have a larger or smaller impact on the posterior alpha factor mean values (e.g., the CCF alpha factor mean values for DCP-BAT-LP based on the 2015 other priors are 30–70% lower than the values based on the generic priors).

Table 8-15. Alpha factors mean value comparison for **pump** component type.

Group size	Alpha factor	**2015 Priors**			**ALL-MDP-FS** Posteriors			**AFW-MDP-FS** Posteriors		
		Generic	**Pump**	Delta	With **Generic** Priors	With **Pump** Priors	Delta	With **Generic** Priors	With **Pump** Priors	Delta
2	α2	2.05E-02	1.12E-02	-45%	1.08E-02	9.69E-03	-10%	3.65E-02	2.46E-02	-33%
3	α2	1.44E-02	8.57E-03	-40%	5.51E-03	5.03E-03	-9%	1.01E-02	7.06E-03	-30%
	α3	4.68E-03	2.00E-03	-57%	5.05E-03	4.04E-03	-20%	1.51E-02	8.55E-03	-43%
4	α2	1.36E-02	7.97E-03	-41%	5.85E-03	5.19E-03	-11%	9.98E-03	6.77E-03	-32%
	α3	4.35E-03	2.35E-03	-46%	3.01E-03	2.49E-03	-17%	7.15E-03	4.24E-03	-41%
	α4	2.50E-03	9.46E-04	-62%	2.07E-03	1.55E-03	-25%	5.79E-03	3.05E-03	-47%

Table 8-16. Alpha factors mean value comparison for **valve** component type.

Group size	Alpha factor	**2015 Priors**			**ALL-MOV-FTOC** Posteriors			**AFW-AOV-FTOC** Posteriors			**ALL-SVV-CC** Posteriors		
		Generic	**Valve**	Delta	With **Generic** Priors	With **Valve** Priors	Delta	With **Generic** Priors	With **Valve** Priors	Delta	With Generic Priors	With **Valve** Priors	Delta
2	α2	2.05E-02	3.54E-02	73%	3.61E-03	3.68E-03	2%	3.38E-02	4.06E-02	20%	2.20E-02	3.73E-02	69%
3	α2	1.44E-02	2.69E-02	87%	4.96E-03	5.71E-03	15%	1.67E-02	2.24E-02	34%	1.63E-02	2.97E-02	82%
	α3	4.68E-03	6.52E-03	39%	8.57E-04	7.77E-04	-9%	9.99E-03	1.21E-02	22%	4.72E-03	6.54E-03	38%
4	α2	1.36E-02	2.36E-02	74%	6.21E-03	6.92E-03	11%	1.14E-02	1.53E-02	34%	1.57E-02	2.69E-02	71%
	α3	4.35E-03	9.05E-03	108%	9.06E-04	1.24E-03	37%	8.35E-03	1.16E-02	39%	4.57E-03	9.32E-03	104%
	α4	2.50E-03	3.00E-03	20%	5.21E-04	4.12E-04	-21%	4.36E-03	5.13E-03	18%	2.47E-03	2.94E-03	19%

Table 8-17. Alpha factors mean value comparison for **strainer** component type.

Group size	Alpha factor	**2015 Priors**			**ALL-TSA-PG** Posteriors		
		Generic	**Strainer**	Delta	With **Generic** Priors	With **Strainer** Priors	Delta
2	α2	2.05E-02	9.68E-02	372%	1.46E-01	2.71E-01	86%
3	α2	1.44E-02	5.07E-02	252%	2.96E-02	6.15E-02	108%
	α3	4.68E-03	2.20E-02	370%	5.89E-02	1.33E-01	125%
4	α2	1.36E-02	4.87E-02	258%	2.55E-02	5.69E-02	123%
	α3	4.35E-03	1.73E-02	298%	2.30E-02	5.38E-02	134%
	α4	2.50E-03	9.86E-03	294%	2.45E-02	5.73E-02	134%

Table 8-18. Alpha factors mean value comparison for **generator** component type.

Group size	Alpha factor	**2015 Priors**			**EPS-EDG-FS** Posteriors			**EPS-EDG-FR** Posteriors		
		Generic	**Generator**	Delta	With **Generic** Priors	With **Generator** Priors	Delta	With **Generic** Priors	With **Generator** Priors	Delta
2	α2	2.05E-02	7.92E-03	-61%	8.28E-03	6.89E-03	-17%	1.38E-02	1.08E-02	-22%
3	α2	1.44E-02	5.17E-03	-64%	4.66E-03	3.34E-03	-28%	1.10E-02	7.59E-03	-31%
	α3	4.68E-03	2.16E-03	-54%	2.68E-03	2.16E-03	-19%	3.48E-03	2.63E-03	-24%
4	α2	1.36E-02	4.03E-03	-70%	3.77E-03	2.29E-03	-39%	7.06E-03	4.16E-03	-41%
	α3	4.35E-03	2.09E-03	-52%	2.25E-03	1.84E-03	-18%	4.55E-03	3.25E-03	-29%
	α4	2.50E-03	8.05E-04	-68%	1.20E-03	8.09E-04	-33%	1.54E-03	9.56E-04	-38%

Table 8-19. Alpha factors mean value comparison for **other** component type.

Group size	Alpha factor	**2015 Priors**			**DCP-BAT-LP** Posteriors		
		Generic	**Other**	Delta	With **Generic** Priors	With **Other** Priors	Delta
2	α2	2.05E-02	9.33E-03	-54%	1.43E-02	8.13E-03	-43%
3	α2	1.44E-02	6.68E-03	-54%	1.25E-02	6.66E-03	-47%
	α3	4.68E-03	1.20E-03	-74%	3.53E-03	1.08E-03	-69%
4	α2	1.36E-02	7.34E-03	-46%	1.28E-02	7.60E-03	-41%
	α3	4.35E-03	1.11E-03	-75%	3.41E-03	9.88E-04	-71%
	α4	2.50E-03	1.56E-03	-37%	1.96E-03	1.40E-03	-29%

9. SUMMARY

CCFs are recognized as significant risk contributors for nuclear power plants. CCF parameters are estimated using a Bayesian update method. With sparse new evidence available in the nuclear power domain, the selection of priors can strongly impact posteriors and is thus a key issue worth investigating. To date, generic priors have been used for estimating all CCF parameters. The most recent set of generic priors was provided in [12], based on failure data collected from 1997 to 2015. Besides using generic priors, an alternative approach is to partition raw data into smaller pools (e.g., by failure cause, component type, or failure mode), then use the data in each pool to develop pool-specific priors in order to better represent pool-specific performance and reduce the uncertainties caused by pool-to-pool variabilities. For example, in [12], five sets of causal CCF priors were developed for the following failure cause groups: component, design, environment, human, and "other." These 2015 causal CCF priors were used to develop 2020 causal CCF parameter estimates that can be applied to the causal alpha factor model. In the meantime, while developing the 2015 generic CCF priors in [12], it was found that different component types could have drastically different alpha factors and could also be analyzed separately.

For ease in comparing the results of the component-specific priors against the results of the 2015 generic priors, this report developed component-specific priors by using the same method as employed to develop the 2015 generic priors, as well as the same set of failure data (1997–2015) utilized in [12].

Section 2 introduces the five component types used in this study. Though any component type could be included in the analysis, to produce statistically valid conclusions the components should not be divided too finely into small classes. Therefore, it is recommended that they be grouped according to the most common component types (i.e., the pump, valve, strainer, and generator categories), with the least common types being lumped together into the "other" category.

Sections 3–7 present the development of CCF prior distributions specific to five component types: pump, valve, strainer, generator, and other equipment, respectively. Three component types (pump, valve, and other) include lethal shock events, and each of the sections corresponding to these types (i.e., Sections 3, 4, and 7) includes a sensitivity study subsection for examining the impacts of using different approaches to count lethal shock events.

In Section 8, several representative CCF templates across the five different component types are chosen, and CCF parameters are estimated for them by using component-specific priors. and the results are compared, which were based on the 2015 generic priors. These alpha factor posterior parameters are compared with those derived from the 2020 CCF parameter estimates [10] which used the generic priors (see Table 8-15 to Table 8-19).

For the reader's convenience, the results of the component-specific CCF priors are summarized below. Table 9-1 to Table 9-10 present the prior distribution parameters and mean values for the pump, valve, strainer, generator, and "other" component types, respectively. For comparison purposes, the 2015 generic prior distribution parameters and mean values developed in [12] are also presented in Table 9-11 and Table 9-12. Table 9-13 compares the mean values of the alpha factors in the component-specific CCF priors against those in the 2015 generic CCF priors.

The comparisons in Sections 8 and 9 led to the following findings:

a. The alpha factor prior mean values vary significantly with component type.
b. The alpha factor prior mean values for the pump, generator, and "other" component types are about 40–70% lower than the 2015 generic prior mean values.
c. The alpha factor prior mean values for the valve component type are about 20–100% higher than the 2015 generic prior mean values.

d. The alpha factor prior mean values for the strainer component type are about 2–3 times higher than the 2015 generic prior mean values.
e. All the alpha factor posterior mean values for the selected CCF templates reflect the same trends as their priors' mean values (i.e., if a prior increases, so does the corresponding posterior; and if a prior decreases, so does its posterior), except in regard to ALL-MOV-FTOC (see also next item).
f. The posterior changes (i.e., deltas) are usually smaller than the prior changes. The abundance of observed data (or "evidence") determines the level of discrepancy between a posterior delta and a prior delta. The more abundant the evidence, the more "resilient" the evidence is in resisting the impact of priors. For cases in which evidence is extremely rare (e.g., ALL-SVV-CC), the posterior changes are almost identical to the prior changes. When evidence is abundant, the posterior changes may be significantly smaller than the prior changes, and even reflect an opposite trend (e.g., ALL-MOV-FTOC).
g. The alpha factor posterior mean values for the pump-, generator-, and "other"-related CCF templates are about 10–70% lower than those obtained using the 2015 generic priors.
h. The alpha factor posterior mean values for the valve-related CCF templates are about 20% lower to 100% higher than those obtained using the 2015 generic priors.
i. The alpha factor posterior mean values for the strainer component type are about 1.0–1.3 times higher than those obtained using the 2015 generic priors.

The above findings confirm and support the original notion—which stemmed from developing the 2015 generic CCF priors [7] several years ago—that different component types could have drastically different alpha factors and should thus be analyzed separately.

This report develops the methodology and argues that component-specific CCF priors would better represent CCF vulnerability over different component types, and should therefore replace the generic priors when conducting CCF parameter estimations in the future. A subsequent step will be to update the RADS CCF application with these component-specific priors and add the capability to estimate CCF parameters based on them.

The following are other observations derived from the study:

a. Sensitivity studies were conducted to examine the impact of distinguishing lethal shocks from non-lethal-shock-but-complete-CCF events (i.e., excluding lethal shocks from the binomial regression and adding the total number of lethal shocks to the final n_k value for each CCCG). There was one pump lethal shock event, two valve lethal shock events, and one "other" lethal shock event. All the lethal shock events occurred in a group size of 2. The sensitivity studies show that if the lethal shock events are excluded from the binomial regression but added to the final n_k value for each CCCG, there will be no impact to a group size of 2, a lesser impact (e.g., 20–40% higher) on smaller group sizes such as size 3 or 4, and a much more significant impact (up to several orders of magnitude) on larger group sizes. Consideration will be given to using this technically more defensible approach in future CCF releases.
b. The numbers of complete CCFs estimated using binomial regression are very close to the actual numbers for all the applicable component types, apart from "other" (i.e., 10 vs. five or four).
c. Although the numbers of complete CCFs estimated using binomial regression are usually very close to the actual numbers of complete CCF events, it should be noted that the numbers of effective data points used in the binomial regression are very low (e.g., 2–4) Some data points were discarded because either the total CCF event number or complete CCF event number was zero. This issue should also be addressed when making future enhancements to this methodology.
d. The intended scope of this study limits the group size to 2–16. However, the very-high-order CCF events (i.e., higher than 16) are present and have not been eliminated from the impact vector

calculations made by the RADS online calculator. These events were eliminated manually from the CCF event pool and excluded them from the binomial regression in the study.

For the Dirichlet distribution used in developing the CCF priors, a special study was conducted and documented in APPENDIX A of this report, with the following insights:

a. The minimally informative Dirichlet distribution is a theoretically justified prior for a set of alpha factors and should be used as a generic prior. The individual alpha factors have beta distributions, but in theory they cannot be statistically independent because the alpha factors must sum to 1.0. The Dirichlet distribution accounts for this dependence. In the work of alpha factor estimates, however, α_1 is nearly 1.0 and all the other alpha factors are very small. In this case, the effect of dependence is negligible. Therefore, assigning independent beta distributions to the alpha factors is an adequate approximation for the analysis.
b. The Dirichlet distribution accounts for the alpha factors' dependence on each other. However, when CCFs are very rare, this dependence is very small and, in practice, can be ignored. That is, the individual beta distributions can be treated as independent distributions, rather than treated together under the same Dirichlet distribution.
c. Further investigation may be necessary to determine how rare CCFs need to be in order to ignore the aforementioned dependence.
d. A full Dirichlet treatment may be preferable in other situations (e.g., multi-way branching in event trees) when it is known that one of several events—each having a probability that is not necessarily small—can occur.

Table 9-1. Estimated alpha factor distribution parameters for the 2015 pump priors.

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	4.25E+01	4.83E-01	4.83E-01	4.25E+01	—	—	—	—	—	—	—	—	—	—	—	—
3	1.18E+02	1.26E+00	1.02E+00	1.18E+02	2.38E-01	1.19E+02	—	—	—	—	—	—	—	—	—	—
4	1.87E+02	2.14E+00	1.51E+00	1.88E+02	4.46E-01	1.89E+02	1.79E-01	1.89E+02	—	—	—	—	—	—	—	—
5	3.75E+02	3.70E+00	2.05E+00	3.77E+02	1.17E+00	3.77E+02	4.07E-01	3.78E+02	6.20E-02	3.79E+02	—	—	—	—	—	—
6	4.90E+02	4.48E+00	1.99E+00	4.92E+02	1.43E+00	4.93E+02	7.33E-01	4.93E+02	2.63E-01	4.94E+02	5.54E-02	4.94E+02	—	—	—	—
7	7.43E+02	6.30E+00	2.40E+00	7.47E+02	1.86E+00	7.47E+02	1.21E+00	7.48E+02	6.00E-01	7.48E+02	2.08E-01	7.49E+02	2.27E-02	7.49E+02	—	—
8	8.68E+02	6.94E+00	2.35E+00	8.72E+02	1.82E+00	8.73E+02	1.37E+00	8.73E+02	8.30E-01	8.74E+02	4.04E-01	8.74E+02	1.31E-01	8.75E+02	2.96E-02	8.75E+02
9	1.23E+03	9.32E+00	2.92E+00	1.24E+03	2.17E+00	1.24E+03	1.78E+00	1.24E+03	1.25E+00	1.24E+03	7.31E-01	1.24E+03	3.44E-01	1.24E+03	1.04E-01	1.24E+03
10	1.54E+03	1.11E+01	3.29E+00	1.55E+03	2.32E+00	1.55E+03	1.98E+00	1.55E+03	1.54E+00	1.55E+03	1.02E+00	1.55E+03	5.85E-01	1.55E+03	2.63E-01	1.55E+03
11	1.89E+03	1.30E+01	3.70E+00	1.90E+03	2.49E+00	1.90E+03	2.13E+00	1.90E+03	1.78E+00	1.90E+03	1.31E+00	1.90E+03	8.49E-01	1.90E+03	4.70E-01	1.91E+03
12	2.29E+03	1.51E+01	4.16E+00	2.30E+03	2.69E+00	2.30E+03	2.26E+00	2.30E+03	1.98E+00	2.30E+03	1.58E+00	2.30E+03	1.12E+00	2.30E+03	7.07E-01	2.30E+03
13	2.74E+03	1.73E+01	4.66E+00	2.75E+03	2.93E+00	2.75E+03	2.39E+00	2.75E+03	2.13E+00	2.75E+03	1.81E+00	2.75E+03	1.39E+00	2.75E+03	9.60E-01	2.75E+03
14	3.24E+03	1.98E+01	5.21E+00	3.25E+03	3.20E+00	3.26E+03	2.54E+00	3.26E+03	2.27E+00	3.26E+03	2.01E+00	3.26E+03	1.64E+00	3.26E+03	1.22E+00	3.26E+03
15	3.79E+03	2.24E+01	5.79E+00	3.81E+03	3.51E+00	3.81E+03	2.70E+00	3.81E+03	2.39E+00	3.81E+03	2.17E+00	3.81E+03	1.86E+00	3.82E+03	1.47E+00	3.82E+03
16	4.42E+03	2.52E+01	6.42E+00	4.43E+03	3.85E+00	4.44E+03	2.90E+00	4.44E+03	2.52E+00	4.44E+03	2.32E+00	4.44E+03	2.06E+00	4.44E+03	1.71E+00	4.44E+03

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	1.03E-02	1.24E+03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	7.42E-02	1.55E+03	7.05E-03	1.55E+03	—	—	—	—	—	—	—	—	—	—	—	—
11	2.02E-01	1.91E+03	5.33E-02	1.91E+03	4.87E-03	1.91E+03	—	—	—	—	—	—	—	—	—	—
12	3.79E-01	2.30E+03	1.55E-01	2.31E+03	3.85E-02	2.31E+03	3.39E-03	2.31E+03	—	—	—	—	—	—	—	—
13	5.90E-01	2.75E+03	3.05E-01	2.75E+03	1.19E-01	2.75E+03	2.80E-02	2.75E+03	2.40E-03	2.75E+03	—	—	—	—	—	—
14	8.24E-01	3.26E+03	4.93E-01	3.26E+03	2.46E-01	3.26E+03	9.13E-02	3.26E+03	2.04E-02	3.26E+03	1.67E-03	3.26E+03	—	—	—	—
15	1.07E+00	3.82E+03	7.07E-01	3.82E+03	4.11E-01	3.82E+03	1.98E-01	3.82E+03	7.03E-02	3.82E+03	1.49E-02	3.82E+03	1.19E-03	3.82E+03	—	—
16	1.32E+00	4.44E+03	9.40E-01	4.44E+03	6.05E-01	4.44E+03	3.43E-01	4.44E+03	1.60E-01	4.44E+03	5.42E-02	4.44E+03	1.10E-02	4.44E+03	8.34E-04	4.44E+03

Table 9-2. Estimated alpha factor mean values for the 2015 pump priors.

Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9888	1.12E-02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9894	8.57E-03	2.00E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9887	7.97E-03	2.35E-03	9.46E-04	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9902	5.41E-03	3.09E-03	1.08E-03	1.64E-04	—	—	—	—	—	—	—	—	—	—	—
6	0.9909	4.03E-03	2.89E-03	1.49E-03	5.32E-04	1.12E-04	—	—	—	—	—	—	—	—	—	—
7	0.9916	3.20E-03	2.48E-03	1.62E-03	8.02E-04	2.78E-04	3.03E-05	—	—	—	—	—	—	—	—	—
8	0.9921	2.69E-03	2.08E-03	1.57E-03	9.49E-04	4.62E-04	1.50E-04	3.38E-05	—	—	—	—	—	—	—	—
9	0.9925	2.35E-03	1.75E-03	1.43E-03	1.01E-03	5.89E-04	2.77E-04	8.39E-05	8.31E-06	—	—	—	—	—	—	—
10	0.9928	2.12E-03	1.50E-03	1.28E-03	9.93E-04	6.58E-04	3.77E-04	1.70E-04	4.79E-05	4.55E-06	—	—	—	—	—	—
11	0.9932	1.94E-03	1.31E-03	1.12E-03	9.36E-04	6.89E-04	4.47E-04	2.46E-04	1.06E-04	2.79E-05	2.55E-06	—	—	—	—	—
12	0.9934	1.81E-03	1.17E-03	9.82E-04	8.60E-04	6.87E-04	4.87E-04	3.07E-04	1.65E-04	6.71E-05	1.67E-05	1.47E-06	—	—	—	—
13	0.9937	1.69E-03	1.06E-03	8.68E-04	7.74E-04	6.58E-04	5.05E-04	3.49E-04	2.15E-04	1.11E-04	4.33E-05	1.02E-05	8.73E-07	—	—	—
14	0.9939	1.60E-03	9.81E-04	7.79E-04	6.96E-04	6.16E-04	5.03E-04	3.74E-04	2.53E-04	1.51E-04	7.55E-05	2.80E-05	6.26E-06	5.12E-07	—	—
15	0.9941	1.52E-03	9.20E-04	7.08E-04	6.27E-04	5.69E-04	4.87E-04	3.85E-04	2.80E-04	1.85E-04	1.08E-04	5.18E-05	1.84E-05	3.90E-06	3.12E-07	—
16	0.9943	1.45E-03	8.66E-04	6.53E-04	5.67E-04	5.22E-04	4.64E-04	3.85E-04	2.97E-04	2.12E-04	1.36E-04	7.73E-05	3.60E-05	1.22E-05	2.48E-06	1.88E-07

Table 9-3. Estimated alpha factor distribution parameters for the 2015 valve priors.

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	1.21E+01	4.44E-01	4.44E-01	1.21E+01												
3	3.46E+01	1.20E+00	9.63E-01	3.48E+01	2.33E-01	3.55E+01										
4	5.39E+01	1.99E+00	1.32E+00	5.46E+01	5.06E-01	5.54E+01	1.68E-01	5.58E+01								
5	9.74E+01	3.27E+00	1.78E+00	9.89E+01	9.92E-01	9.96E+01	4.30E-01	1.00E+02	7.45E-02	1.01E+02						
6	1.26E+02	3.97E+00	1.75E+00	1.28E+02	1.20E+00	1.29E+02	6.71E-01	1.29E+02	2.84E-01	1.30E+02	7.11E-02	1.30E+02				
7	1.83E+02	5.34E+00	2.07E+00	1.87E+02	1.40E+00	1.87E+02	1.04E+00	1.88E+02	5.94E-01	1.88E+02	2.13E-01	1.89E+02	3.79E-02	1.89E+02		
8	1.90E+02	5.29E+00	1.86E+00	1.93E+02	1.18E+00	1.94E+02	9.40E-01	1.94E+02	7.22E-01	1.94E+02	3.67E-01	1.95E+02	1.15E-01	1.95E+02	1.15E-01	1.95E+02
9	3.08E+02	7.97E+00	2.68E+00	3.14E+02	1.61E+00	3.15E+02	1.34E+00	3.15E+02	1.09E+00	3.15E+02	7.38E-01	3.15E+02	3.76E-01	3.16E+02	1.11E-01	3.16E+02
10	3.77E+02	9.26E+00	2.97E+00	3.83E+02	1.74E+00	3.85E+02	1.41E+00	3.85E+02	1.22E+00	3.85E+02	9.30E-01	3.85E+02	5.98E-01	3.86E+02	2.95E-01	3.86E+02
11	4.01E+02	9.43E+00	2.89E+00	4.08E+02	1.68E+00	4.09E+02	1.30E+00	4.09E+02	1.16E+00	4.10E+02	9.62E-01	4.10E+02	7.00E-01	4.10E+02	4.35E-01	4.10E+02
12	4.99E+02	1.12E+01	3.30E+00	5.07E+02	1.91E+00	5.09E+02	1.44E+00	5.09E+02	1.27E+00	5.09E+02	1.13E+00	5.09E+02	8.84E-01	5.10E+02	6.28E-01	5.10E+02
13	6.30E+02	1.35E+01	3.80E+00	6.40E+02	2.24E+00	6.41E+02	1.66E+00	6.42E+02	1.40E+00	6.42E+02	1.32E+00	6.42E+02	1.11E+00	6.43E+02	8.23E-01	6.43E+02
14	6.92E+02	1.42E+01	3.84E+00	7.02E+02	2.29E+00	7.03E+02	1.70E+00	7.04E+02	1.37E+00	7.04E+02	1.25E+00	7.04E+02	1.23E+00	7.04E+02	8.81E-01	7.05E+02
15	8.39E+02	1.65E+01	4.34E+00	8.51E+02	2.59E+00	8.53E+02	1.95E+00	8.54E+02	1.51E+00	8.54E+02	1.37E+00	8.54E+02	1.33E+00	8.54E+02	1.13E+00	8.54E+02
16	8.35E+02	1.58E+01	4.05E+00	8.46E+02	2.39E+00	8.48E+02	1.85E+00	8.49E+02	1.38E+00	8.49E+02	1.24E+00	8.49E+02	1.18E+00	8.49E+02	1.09E+00	8.49E+02

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	1.87E-02	3.16E+02														
10	8.37E-02	3.86E+02	1.49E-02	3.86E+02												
11	2.04E-01	4.10E+02	5.72E-02	4.11E+02	3.64E-02	4.11E+02										
12	3.76E-01	5.10E+02	1.67E-01	5.10E+02	4.77E-02	5.11E+02	2.11E-02	5.11E+02								
13	5.89E-01	6.43E+02	3.29E-01	6.43E+02	1.42E-01	6.43E+02	4.20E-02	6.44E+02	8.39E-03	6.44E+02						
14	7.05E-01	7.05E+02	4.81E-01	7.05E+02	2.49E-01	7.05E+02	1.08E-01	7.06E+02	3.33E-02	7.06E+02	1.36E-02	7.06E+02				
15	8.27E-01	8.55E+02	6.93E-01	8.55E+02	4.22E-01	8.55E+02	2.11E-01	8.55E+02	9.48E-02	8.55E+02	2.97E-02	8.56E+02	5.91E-03	8.56E+02		
16	8.72E-01	8.49E+02	6.37E-01	8.50E+02	5.87E-01	8.50E+02	2.77E-01	8.50E+02	1.55E-01	8.50E+02	6.96E-02	8.50E+02	2.22E-02	8.50E+02	3.38E-02	8.50E+02

Table 9-4. Estimated alpha factor mean values for the 2015 valve priors.

Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9650	3.54E-02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9670	2.69E-02	6.52E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9640	2.36E-02	9.04E-03	3.00E-03	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9670	1.77E-02	9.85E-03	4.27E-03	7.40E-04	—	—	—	—	—	—	—	—	—	—	—
6	0.9690	1.35E-02	9.26E-03	5.17E-03	2.19E-03	5.48E-04	—	—	—	—	—	—	—	—	—	—
7	0.9720	1.09E-02	7.39E-03	5.50E-03	3.15E-03	1.13E-03	2.01E-04	—	—	—	—	—	—	—	—	—
8	0.9730	9.51E-03	6.03E-03	4.82E-03	3.70E-03	1.88E-03	5.90E-04	5.90E-04	—	—	—	—	—	—	—	—
9	0.9750	8.49E-03	5.09E-03	4.25E-03	3.43E-03	2.33E-03	1.19E-03	3.51E-04	5.90E-05	—	—	—	—	—	—	—
10	0.9760	7.69E-03	4.49E-03	3.66E-03	3.15E-03	2.41E-03	1.55E-03	7.63E-04	2.17E-04	3.86E-05	—	—	—	—	—	—
11	0.9770	7.05E-03	4.10E-03	3.16E-03	2.82E-03	2.34E-03	1.70E-03	1.06E-03	4.96E-04	1.39E-04	8.87E-05	—	—	—	—	—
12	0.9780	6.45E-03	3.74E-03	2.82E-03	2.48E-03	2.22E-03	1.73E-03	1.23E-03	7.36E-04	3.27E-04	9.35E-05	4.12E-05	—	—	—	—
13	0.9790	5.90E-03	3.48E-03	2.58E-03	2.17E-03	2.04E-03	1.72E-03	1.28E-03	9.15E-04	5.11E-04	2.20E-04	6.53E-05	1.30E-05	—	—	—
14	0.9800	5.45E-03	3.24E-03	2.40E-03	1.95E-03	1.77E-03	1.74E-03	1.25E-03	9.99E-04	6.81E-04	3.53E-04	1.53E-04	4.71E-05	1.93E-05	—	—
15	0.9810	5.07E-03	3.02E-03	2.27E-03	1.77E-03	1.60E-03	1.55E-03	1.32E-03	9.66E-04	8.10E-04	4.94E-04	2.46E-04	1.11E-04	3.48E-05	6.91E-06	—
16	0.9810	4.76E-03	2.81E-03	2.18E-03	1.62E-03	1.45E-03	1.39E-03	1.28E-03	1.03E-03	7.49E-04	6.90E-04	3.26E-04	1.83E-04	8.18E-05	2.61E-05	3.98E-05

Table 9-5. Estimated alpha factor distribution parameters for the 2015 strainer priors.

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	3.22E+00	3.45E-01	3.45E-01	3.22E+00	—	—	—	—	—	—	—	—	—	—	—	—
3	1.23E+01	9.58E-01	6.68E-01	1.25E+01	2.90E-01	1.29E+01	—	—	—	—	—	—	—	—	—	—
4	2.09E+01	1.72E+00	1.10E+00	2.15E+01	3.91E-01	2.22E+01	2.23E-01	2.24E+01	—	—	—	—	—	—	—	—
5	4.88E+01	3.50E+00	1.89E+00	5.04E+01	1.21E+00	5.11E+01	3.44E-01	5.20E+01	6.39E-02	5.23E+01	—	—	—	—	—	—
6	4.33E+01	3.18E+00	1.07E+00	4.54E+01	1.17E+00	4.53E+01	4.62E-01	4.60E+01	1.21E-01	4.64E+01	3.60E-01	4.61E+01	—	—	—	—
7	8.89E+01	5.24E+00	1.61E+00	9.25E+01	1.79E+00	9.24E+01	1.11E+00	9.30E+01	5.37E-01	9.36E+01	1.45E-01	9.40E+01	5.28E-02	9.41E+01	—	—
8	1.36E+02	7.25E+00	1.99E+00	1.41E+02	1.99E+00	1.41E+02	1.67E+00	1.41E+02	9.62E-01	1.42E+02	4.96E-01	1.43E+02	1.33E-01	1.43E+02	1.60E-02	1.43E+02
9	1.71E+02	8.42E+00	2.14E+00	1.77E+02	1.90E+00	1.77E+02	1.85E+00	1.77E+02	1.26E+00	1.78E+02	7.70E-01	1.78E+02	3.91E-01	1.79E+02	1.02E-01	1.79E+02
10	2.11E+02	9.72E+00	2.37E+00	2.19E+02	1.83E+00	2.19E+02	1.96E+00	2.19E+02	1.51E+00	2.19E+02	1.02E+00	2.20E+02	6.44E-01	2.20E+02	3.10E-01	2.21E+02
11	2.57E+02	1.12E+01	2.69E+00	2.66E+02	1.74E+00	2.67E+02	2.07E+00	2.66E+02	1.69E+00	2.67E+02	1.26E+00	2.67E+02	8.61E-01	2.67E+02	5.47E-01	2.68E+02
12	2.08E+02	8.82E+00	2.12E+00	2.15E+02	1.07E+00	2.16E+02	1.49E+00	2.15E+02	1.22E+00	2.16E+02	9.94E-01	2.16E+02	7.17E-01	2.16E+02	5.08E-01	2.16E+02
13	3.64E+02	1.44E+01	3.19E+00	3.75E+02	2.09E+00	3.76E+02	2.09E+00	3.76E+02	1.98E+00	3.76E+02	1.65E+00	3.77E+02	1.26E+00	3.77E+02	9.26E-01	3.77E+02
14	4.35E+02	1.60E+01	3.32E+00	4.48E+02	2.06E+00	4.49E+02	2.06E+00	4.49E+02	2.12E+00	4.49E+02	1.86E+00	4.49E+02	1.48E+00	4.50E+02	1.12E+00	4.50E+02
15	5.15E+02	1.76E+01	3.47E+00	5.29E+02	2.05E+00	5.30E+02	2.05E+00	5.30E+02	2.21E+00	5.30E+02	2.05E+00	5.30E+02	1.71E+00	5.31E+02	1.32E+00	5.31E+02
16	6.02E+02	1.94E+01	3.63E+00	6.18E+02	2.08E+00	6.20E+02	2.08E+00	6.20E+02	2.25E+00	6.20E+02	2.20E+00	6.20E+02	1.92E+00	6.20E+02	1.53E+00	6.20E+02

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	1.17E-02	1.79E+02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	7.80E-02	2.21E+02	8.43E-03	2.21E+02	—	—	—	—	—	—	—	—	—	—	—	—
11	2.46E-01	2.68E+02	5.94E-02	2.68E+02	6.10E-03	2.68E+02	—	—	—	—	—	—	—	—	—	—
12	3.13E-01	2.17E+02	1.31E-01	2.17E+02	3.03E-02	2.17E+02	2.34E-01	2.17E+02	—	—	—	—	—	—	—	—
13	6.66E-01	3.78E+02	3.88E-01	3.78E+02	1.52E-01	3.78E+02	3.37E-02	3.78E+02	3.10E-03	3.78E+02	—	—	—	—	—	—
14	8.51E-01	4.50E+02	6.03E-01	4.51E+02	3.30E-01	4.51E+02	1.21E-01	4.51E+02	2.57E-02	4.51E+02	2.27E-03	4.51E+02	—	—	—	—
15	1.02E+00	5.31E+02	7.94E-01	5.32E+02	5.41E-01	5.32E+02	2.78E-01	5.32E+02	9.61E-02	5.32E+02	1.95E-02	5.32E+02	1.63E-03	5.32E+02	—	—
16	1.19E+00	6.21E+02	9.53E-01	6.21E+02	7.39E-01	6.21E+02	4.78E-01	6.21E+02	2.31E-01	6.22E+02	7.56E-02	6.22E+02	1.46E-02	6.22E+02	1.19E-03	6.22E+02

Table 9-6. Estimated alpha factor mean values for the 2015 strainer priors.

Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9030	9.69E-02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9270	5.06E-02	2.20E-02	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9240	4.89E-02	1.73E-02	9.88E-03	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9330	3.61E-02	2.31E-02	6.58E-03	1.22E-03	—	—	—	—	—	—	—	—	—	—	—
6	0.9320	2.31E-02	2.51E-02	9.94E-03	2.60E-03	7.74E-03	—	—	—	—	—	—	—	—	—	—
7	0.9440	1.71E-02	1.90E-02	1.18E-02	5.71E-03	1.54E-03	5.61E-04	—	—	—	—	—	—	—	—	—
8	0.9490	1.39E-02	1.39E-02	1.16E-02	6.73E-03	3.47E-03	9.27E-04	1.12E-04	—	—	—	—	—	—	—	—
9	0.9530	1.19E-02	1.06E-02	1.03E-02	7.05E-03	4.30E-03	2.18E-03	5.69E-04	6.51E-05	—	—	—	—	—	—	—
10	0.9560	1.07E-02	8.26E-03	8.88E-03	6.84E-03	4.61E-03	2.91E-03	1.40E-03	3.53E-04	3.82E-05	—	—	—	—	—	—
11	0.9580	1.00E-02	6.47E-03	7.71E-03	6.30E-03	4.68E-03	3.21E-03	2.04E-03	9.16E-04	2.21E-04	2.27E-05	—	—	—	—	—
12	0.9590	9.76E-03	4.92E-03	6.88E-03	5.61E-03	4.58E-03	3.30E-03	2.34E-03	1.44E-03	6.03E-04	1.40E-04	1.08E-03	—	—	—	—
13	0.9620	8.42E-03	5.53E-03	5.53E-03	5.23E-03	4.36E-03	3.32E-03	2.45E-03	1.76E-03	1.03E-03	4.01E-04	8.90E-05	8.20E-06	—	—	—
14	0.9650	7.37E-03	4.57E-03	4.57E-03	4.70E-03	4.13E-03	3.28E-03	2.47E-03	1.89E-03	1.34E-03	7.32E-04	2.69E-04	5.69E-05	5.02E-06	—	—
15	0.9670	6.52E-03	3.86E-03	3.86E-03	4.14E-03	3.85E-03	3.21E-03	2.47E-03	1.91E-03	1.49E-03	1.02E-03	5.21E-04	1.80E-04	3.66E-05	3.07E-06	—
16	0.9690	5.84E-03	3.34E-03	3.34E-03	3.62E-03	3.54E-03	3.09E-03	2.46E-03	1.91E-03	1.53E-03	1.19E-03	7.69E-04	3.71E-04	1.22E-04	2.35E-05	1.92E-06

Table 9-7. Estimated alpha factor distribution parameters for the 2015 generator priors.

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	6.11E+01	4.88E-01	4.88E-01	6.11E+01	—	—	—	—	—	—	—	—	—	—	—	—
3	1.47E+02	1.08E+00	7.64E-01	1.47E+02	3.20E-01	1.48E+02	—	—	—	—	—	—	—	—	—	—
4	2.61E+02	1.82E+00	1.06E+00	2.62E+02	5.50E-01	2.62E+02	2.11E-01	2.62E+02	—	—	—	—	—	—	—	—
5	4.21E+02	2.60E+00	1.18E+00	4.22E+02	7.98E-01	4.23E+02	4.79E-01	4.23E+02	1.36E-01	4.23E+02	—	—	—	—	—	—
6	6.26E+02	3.55E+00	1.44E+00	6.28E+02	9.30E-01	6.29E+02	7.22E-01	6.29E+02	3.79E-01	6.29E+02	8.41E-02	6.30E+02	—	—	—	—
7	8.84E+02	4.72E+00	1.83E+00	8.87E+02	1.03E+00	8.88E+02	8.85E-01	8.88E+02	6.44E-01	8.88E+02	2.80E-01	8.88E+02	5.09E-02	8.89E+02	—	—
8	1.20E+03	6.16E+00	2.37E+00	1.21E+03	1.17E+00	1.21E+03	9.84E-01	1.21E+03	8.65E-01	1.21E+03	5.44E-01	1.21E+03	1.97E-01	1.21E+03	3.03E-02	1.21E+03
9	1.60E+03	7.91E+00	3.05E+00	1.60E+03	1.38E+00	1.61E+03	1.06E+00	1.61E+03	1.02E+00	1.61E+03	8.11E-01	1.61E+03	4.35E-01	1.61E+03	1.34E-01	1.61E+03
10	2.08E+03	1.00E+01	3.89E+00	2.09E+03	1.69E+00	2.09E+03	1.13E+00	2.09E+03	1.12E+00	2.09E+03	1.04E+00	2.09E+03	7.21E-01	2.09E+03	3.32E-01	2.09E+03
11	2.67E+03	1.25E+01	4.87E+00	2.67E+03	2.12E+00	2.68E+03	1.24E+00	2.68E+03	1.18E+00	2.68E+03	1.20E+00	2.68E+03	1.00E+00	2.68E+03	6.09E-01	2.68E+03
12	3.37E+03	1.55E+01	6.01E+00	3.38E+03	2.68E+00	3.38E+03	1.41E+00	3.39E+03	1.23E+00	3.39E+03	1.31E+00	3.39E+03	1.24E+00	3.39E+03	9.25E-01	3.39E+03
13	4.23E+03	1.91E+01	7.33E+00	4.24E+03	3.40E+00	4.25E+03	1.67E+00	4.25E+03	1.30E+00	4.25E+03	1.38E+00	4.25E+03	1.43E+00	4.25E+03	1.24E+00	4.25E+03
14	5.22E+03	2.31E+01	8.76E+00	5.24E+03	4.27E+00	5.24E+03	2.01E+00	5.25E+03	1.39E+00	5.25E+03	1.42E+00	5.25E+03	1.55E+00	5.25E+03	1.50E+00	5.25E+03
15	6.43E+03	2.80E+01	1.04E+01	6.45E+03	5.33E+00	6.45E+03	2.48E+00	6.45E+03	1.53E+00	6.46E+03	1.46E+00	6.46E+03	1.63E+00	6.46E+03	1.71E+00	6.46E+03
16	7.99E+03	3.41E+01	1.24E+01	8.01E+03	6.70E+00	8.01E+03	3.15E+00	8.02E+03	1.77E+00	8.02E+03	1.55E+00	8.02E+03	1.71E+00	8.02E+03	1.89E+00	8.02E+03

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	1.79E-02	1.61E+03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	8.92E-02	2.09E+03	1.05E-02	2.09E+03	—	—	—	—	—	—	—	—	—	—	—	—
11	2.45E-01	2.68E+03	5.81E-02	2.68E+03	6.10E-03	2.68E+03	—	—	—	—	—	—	—	—	—	—
12	4.94E-01	3.39E+03	1.76E-01	3.39E+03	3.72E-02	3.39E+03	3.54E-03	3.39E+03	—	—	—	—	—	—	—	—
13	8.16E-01	4.25E+03	3.87E-01	4.25E+03	1.23E-01	4.25E+03	2.36E-02	4.25E+03	2.00E-03	4.25E+03	—	—	—	—	—	—
14	1.17E+00	5.25E+03	6.87E-01	5.25E+03	2.92E-01	5.25E+03	8.42E-02	5.25E+03	1.47E-02	5.25E+03	1.21E-03	5.25E+03	—	—	—	—
15	1.51E+00	6.46E+03	1.06E+00	6.46E+03	5.62E-01	6.46E+03	2.16E-01	6.46E+03	5.68E-02	6.46E+03	9.14E-03	6.46E+03	6.93E-04	6.46E+03	—	—
16	1.85E+00	8.02E+03	1.48E+00	8.02E+03	9.40E-01	8.02E+03	4.52E-01	8.02E+03	1.59E-01	8.02E+03	3.84E-02	8.02E+03	5.65E-03	8.02E+03	3.23E-04	8.02E+03

Table 9-8. Estimated alpha factor mean values for the 2015 generator priors.

Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9921	7.92E-03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9927	5.17E-03	2.16E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9931	4.02E-03	2.10E-03	8.02E-04	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9939	2.79E-03	1.88E-03	1.13E-03	3.20E-04	—	—	—	—	—	—	—	—	—	—	—
6	0.9944	2.28E-03	1.48E-03	1.15E-03	6.02E-04	1.33E-04	—	—	—	—	—	—	—	—	—	—
7	0.9947	2.06E-03	1.16E-03	9.96E-04	7.25E-04	3.15E-04	5.73E-05	—	—	—	—	—	—	—	—	—
8	0.9949	1.96E-03	9.69E-04	8.13E-04	7.14E-04	4.49E-04	1.63E-04	2.51E-05	—	—	—	—	—	—	—	—
9	0.9951	1.90E-03	8.61E-04	6.57E-04	6.34E-04	5.05E-04	2.71E-04	8.36E-05	1.11E-05	—	—	—	—	—	—	—
10	0.9952	1.86E-03	8.09E-04	5.41E-04	5.34E-04	4.95E-04	3.45E-04	1.59E-04	4.27E-05	5.01E-06	—	—	—	—	—	—
11	0.9953	1.82E-03	7.91E-04	4.64E-04	4.40E-04	4.48E-04	3.75E-04	2.27E-04	9.16E-05	2.17E-05	2.28E-06	—	—	—	—	—
12	0.9954	1.77E-03	7.92E-04	4.18E-04	3.63E-04	3.86E-04	3.67E-04	2.73E-04	1.46E-04	5.19E-05	1.10E-05	1.05E-06	—	—	—	—
13	0.9955	1.72E-03	8.01E-04	3.93E-04	3.05E-04	3.24E-04	3.37E-04	2.91E-04	1.92E-04	9.11E-05	2.90E-05	5.54E-06	4.70E-07	—	—	—
14	0.9956	1.67E-03	8.14E-04	3.84E-04	2.64E-04	2.70E-04	2.96E-04	2.86E-04	2.22E-04	1.31E-04	5.57E-05	1.60E-05	2.80E-06	2.30E-07	—	—
15	0.9957	1.61E-03	8.26E-04	3.85E-04	2.37E-04	2.27E-04	2.53E-04	2.65E-04	2.34E-04	1.64E-04	8.70E-05	3.35E-05	8.80E-06	1.42E-06	1.07E-07	—
16	0.9957	1.55E-03	8.36E-04	3.93E-04	2.21E-04	1.93E-04	2.14E-04	2.36E-04	2.30E-04	1.85E-04	1.17E-04	5.64E-05	1.98E-05	4.79E-06	7.04E-07	4.02E-08

Table 9-9. Estimated alpha factor distribution parameters for the 2015 “other” priors.

Group Size	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4	a_5	b_5	a_6	b_6	a_7	b_7	a_8	b_8
2	5.16E+01	4.86E-01	4.86E-01	5.16E+01	—	—	—	—	—	—	—	—	—	—	—	—
3	1.73E+02	1.38E+00	1.17E+00	1.74E+02	2.09E-01	1.74E+02	—	—	—	—	—	—	—	—	—	—
4	2.10E+02	2.12E+00	1.56E+00	2.11E+02	2.35E-01	2.12E+02	3.32E-01	2.12E+02	—	—	—	—	—	—	—	—
5	7.49E+02	5.86E+00	3.80E+00	7.51E+02	1.68E+00	7.54E+02	3.51E-01	7.55E+02	2.72E-02	7.55E+02	—	—	—	—	—	—
6	4.85E+02	3.88E+00	1.95E+00	4.87E+02	1.06E+00	4.88E+02	4.48E-01	4.89E+02	1.02E-01	4.89E+02	3.22E-01	4.89E+02	—	—	—	—
7	1.41E+03	9.52E+00	4.32E+00	1.42E+03	2.83E+00	1.42E+03	1.60E+00	1.42E+03	6.16E-01	1.42E+03	1.36E-01	1.42E+03	9.31E-03	1.42E+03	—	—
8	1.17E+03	7.46E+00	2.96E+00	1.18E+03	2.01E+00	1.18E+03	1.38E+00	1.18E+03	7.13E-01	1.18E+03	2.57E-01	1.18E+03	5.29E-02	1.18E+03	9.69E-02	1.18E+03
9	2.51E+03	1.46E+01	5.20E+00	2.52E+03	3.70E+00	2.52E+03	2.79E+00	2.52E+03	1.76E+00	2.52E+03	8.44E-01	2.52E+03	2.84E-01	2.52E+03	5.30E-02	2.52E+03
10	3.25E+03	1.78E+01	5.80E+00	3.27E+03	4.13E+00	3.27E+03	3.29E+00	3.27E+03	2.37E+00	3.27E+03	1.38E+00	3.27E+03	6.22E-01	3.27E+03	1.93E-01	3.27E+03
11	4.16E+03	2.15E+01	6.58E+00	4.17E+03	4.60E+00	4.17E+03	3.73E+00	4.17E+03	2.96E+00	4.17E+03	1.98E+00	4.18E+03	1.09E+00	4.18E+03	4.57E-01	4.18E+03
12	3.02E+03	1.51E+01	4.35E+00	3.03E+03	2.96E+00	3.04E+03	2.39E+00	3.04E+03	2.03E+00	3.04E+03	1.50E+00	3.04E+03	9.48E-01	3.04E+03	4.90E-01	3.04E+03
13	6.72E+03	3.17E+01	8.95E+00	6.74E+03	5.95E+00	6.75E+03	4.69E+00	6.75E+03	4.14E+00	6.75E+03	3.32E+00	6.75E+03	2.32E+00	6.75E+03	1.39E+00	6.75E+03
14	8.32E+03	3.77E+01	1.04E+01	8.34E+03	6.78E+00	8.35E+03	5.13E+00	8.35E+03	4.66E+00	8.35E+03	3.95E+00	8.35E+03	3.00E+00	8.35E+03	2.00E+00	8.35E+03
15	9.73E+03	4.26E+01	1.14E+01	9.77E+03	7.46E+00	9.77E+03	5.34E+00	9.77E+03	4.93E+00	9.77E+03	4.35E+00	9.77E+03	3.52E+00	9.77E+03	2.56E+00	9.77E+03
16	6.00E+03	2.70E+01	6.64E+00	6.02E+03	4.39E+00	6.03E+03	2.95E+00	6.03E+03	2.75E+00	6.03E+03	2.49E+00	6.03E+03	2.12E+00	6.03E+03	1.64E+00	6.03E+03

Group Size	a_9	b_9	a_{10}	b_{10}	a_{11}	b_{11}	a_{12}	b_{12}	a_{13}	b_{13}	a_{14}	b_{14}	a_{15}	b_{15}	a_{16}	b_{16}
9	3.21E-03	2.52E+03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	3.29E-02	3.27E+03	1.88E-03	3.27E+03	—	—	—	—	—	—	—	—	—	—	—	—
11	1.30E-01	4.18E+03	2.07E-02	4.18E+03	1.09E-03	4.18E+03	—	—	—	—	—	—	—	—	—	—
12	1.91E-01	3.04E+03	4.94E-02	3.04E+03	7.27E-03	3.04E+03	1.60E-01	3.04E+03	—	—	—	—	—	—	—	—
13	6.76E-01	6.75E+03	2.43E-01	6.75E+03	5.82E-02	6.75E+03	7.61E-03	6.75E+03	2.98E-04	6.75E+03	—	—	—	—	—	—
14	1.14E+00	8.35E+03	5.18E-01	8.35E+03	1.71E-01	8.35E+03	3.77E-02	8.35E+03	4.63E-03	8.35E+03	1.71E-04	8.35E+03	—	—	—	—
15	1.64E+00	9.78E+03	8.80E-01	9.78E+03	3.71E-01	9.78E+03	1.14E-01	9.78E+03	2.30E-02	9.78E+03	2.62E-03	9.78E+03	1.87E-04	9.78E+03	—	—
16	1.15E+00	6.03E+03	7.03E-01	6.03E+03	3.55E-01	6.03E+03	1.39E-01	6.03E+03	3.94E-02	6.03E+03	7.37E-03	6.03E+03	7.58E-04	6.03E+03	1.67E+00	6.03E+03

Table 9-10. Estimated alpha factor mean values for the 2015 “other” priors.

Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9910	9.32E-03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9920	6.69E-03	1.20E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9900	7.33E-03	1.10E-03	1.56E-03	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9920	5.03E-03	2.23E-03	4.65E-04	3.60E-05	—	—	—	—	—	—	—	—	—	—	—
6	0.9920	3.99E-03	2.17E-03	9.17E-04	2.09E-04	6.58E-04	—	—	—	—	—	—	—	—	—	—
7	0.9930	3.04E-03	1.99E-03	1.13E-03	4.33E-04	9.57E-05	6.54E-06	—	—	—	—	—	—	—	—	—
8	0.9940	2.50E-03	1.70E-03	1.17E-03	6.04E-04	2.17E-04	4.48E-05	8.20E-05	—	—	—	—	—	—	—	—
9	0.9940	2.06E-03	1.47E-03	1.10E-03	6.98E-04	3.35E-04	1.12E-04	2.10E-05	1.27E-06	—	—	—	—	—	—	—
10	0.9950	1.77E-03	1.26E-03	1.00E-03	7.25E-04	4.23E-04	1.90E-04	5.91E-05	1.00E-05	5.74E-07	—	—	—	—	—	—
11	0.9950	1.57E-03	1.10E-03	8.93E-04	7.09E-04	4.75E-04	2.60E-04	1.09E-04	3.10E-05	4.96E-06	2.61E-07	—	—	—	—	—
12	0.9950	1.43E-03	9.75E-04	7.88E-04	6.67E-04	4.95E-04	3.12E-04	1.61E-04	6.29E-05	1.63E-05	2.39E-06	5.28E-05	—	—	—	—
13	0.9950	1.33E-03	8.81E-04	6.94E-04	6.13E-04	4.91E-04	3.44E-04	2.06E-04	1.00E-04	3.60E-05	8.62E-06	1.13E-06	4.42E-08	—	—	—
14	0.9950	1.24E-03	8.12E-04	6.14E-04	5.58E-04	4.72E-04	3.59E-04	2.40E-04	1.36E-04	6.20E-05	2.05E-05	4.52E-06	5.54E-07	2.05E-08	—	—
15	0.9960	1.17E-03	7.63E-04	5.46E-04	5.04E-04	4.45E-04	3.60E-04	2.62E-04	1.67E-04	9.01E-05	3.79E-05	1.16E-05	2.36E-06	2.68E-07	1.92E-08	—
16	0.9960	1.10E-03	7.28E-04	4.88E-04	4.56E-04	4.14E-04	3.51E-04	2.72E-04	1.91E-04	1.17E-04	5.89E-05	2.31E-05	6.54E-06	1.22E-06	1.26E-07	2.77E-04

Table 9-11. Estimated alpha factor distribution parameters for the 2015 generic priors [12].

Group Size	α_1	b_1	α_2	b_2	α_3	b_3	α_4	b_4	α_5	b_5	α_6	b_6	α_7	b_7	α_8	b_8
2	2.2413E+01	4.6853E-01	4.6853E-01	2.2413E+01	—	—	—	—	—	—	—	—	—	—	—	—
3	5.7979E+01	1.1280E+00	8.5122E-01	5.8255E+01	2.7682E-01	5.8830E+01	—	—	—	—	—	—	—	—	—	—
4	9.0676E+01	1.8936E+00	1.2597E+00	9.1310E+01	4.0244E-01	9.2167E+01	2.3148E-01	9.2338E+01	—	—	—	—	—	—	—	—
5	1.9084E+02	3.4322E+00	1.9242E+00	1.9235E+02	1.0490E+00	1.9322E+02	3.8224E-01	1.9389E+02	7.6743E-02	1.9420E+02	—	—	—	—	—	—
6	2.2522E+02	3.8349E+00	1.7011E+00	2.2735E+02	1.2070E+00	2.2785E+02	5.9596E-01	2.2846E+02	2.2109E-01	2.2883E+02	1.0978E-01	2.2895E+02	—	—	—	—
7	3.7180E+02	5.7474E+00	2.2432E+00	3.7530E+02	1.6295E+00	3.7591E+02	1.0829E+00	3.7646E+02	5.6537E-01	3.7698E+02	1.9159E-01	3.7735E+02	3.4801E-02	3.7751E+02	—	—
8	3.9002E+02	5.7256E+00	2.0181E+00	3.9373E+02	1.3905E+00	3.9436E+02	1.0621E+00	3.9469E+02	7.0259E-01	3.9505E+02	3.4974E-01	3.9540E+02	1.0784E-01	3.9564E+02	9.4689E-02	3.9565E+02
9	6.3746E+02	8.7061E+00	2.9123E+00	6.4325E+02	1.9037E+00	6.4426E+02	1.5622E+00	6.4460E+02	1.1410E+00	6.4502E+02	7.1624E-01	6.4545E+02	3.5346E-01	6.4581E+02	1.0257E-01	6.4606E+02
10	7.8579E+02	1.0194E+01	3.2496E+00	7.9274E+02	2.0278E+00	7.9396E+02	1.6882E+00	7.9430E+02	1.3430E+00	7.9465E+02	9.4492E-01	7.9504E+02	5.7852E-01	7.9541E+02	2.7464E-01	7.9571E+02
11	8.3890E+02	1.0411E+01	3.1974E+00	8.4611E+02	1.9192E+00	8.4739E+02	1.5777E+00	8.4773E+02	1.3230E+00	8.4799E+02	1.0162E+00	8.4829E+02	6.9674E-01	8.4861E+02	4.1654E-01	8.4889E+02
12	9.5624E+02	1.1373E+01	3.3926E+00	9.6422E+02	1.9565E+00	9.6566E+02	1.6063E+00	9.6601E+02	1.3579E+00	9.6626E+02	1.1274E+00	9.6649E+02	8.3049E-01	9.6679E+02	5.6343E-01	9.6705E+02
13	1.3364E+03	1.5165E+01	4.3599E+00	1.3472E+03	2.5405E+00	1.3491E+03	1.9946E+00	1.3496E+03	1.7085E+00	1.3499E+03	1.4876E+00	1.3501E+03	1.1767E+00	1.3504E+03	8.4449E-01	1.3508E+03
14	1.4630E+03	1.5941E+01	4.4270E+00	1.4746E+03	2.6060E+00	1.4764E+03	1.9761E+00	1.4770E+03	1.6884E+00	1.4773E+03	1.4813E+00	1.4775E+03	1.2978E+00	1.4777E+03	9.3977E-01	1.4780E+03
15	1.7967E+03	1.8836E+01	5.0795E+00	1.8104E+03	3.0142E+00	1.8125E+03	2.2353E+00	1.8133E+03	1.8743E+00	1.8136E+03	1.6773E+00	1.8138E+03	1.4896E+00	1.8140E+03	1.2032E+00	1.8143E+03
16	1.6355E+03	1.6615E+01	4.3479E+00	1.6478E+03	2.5912E+00	1.6495E+03	1.9035E+00	1.6502E+03	1.5518E+00	1.6506E+03	1.3999E+00	1.6507E+03	1.2640E+00	1.6508E+03	1.0806E+00	1.6510E+03

Group Size	α_9	b_9	α_{10}	b_{10}	α_{11}	b_{11}	α_{12}	b_{12}	α_{13}	b_{13}	α_{14}	b_{14}	α_{15}	b_{15}	α_{16}	b_{16}
9	1.4617E-02	6.4615E+02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	7.5861E-02	7.9591E+02	1.1044E-02	7.9598E+02	—	—	—	—	—	—	—	—	—	—	—	—
11	1.8754E-01	8.4912E+02	5.0164E-02	8.4926E+02	2.6481E-02	8.4928E+02	—	—	—	—	—	—	—	—	—	—
12	3.2539E-01	9.6729E+02	1.3853E-01	9.6748E+02	3.6653E-02	9.6758E+02	3.7350E-02	9.6758E+02	—	—	—	—	—	—	—	—
13	5.7282E-01	1.3510E+03	3.1280E-01	1.3513E+03	1.2760E-01	1.3515E+03	3.3982E-02	1.3516E+03	5.4449E-03	1.3516E+03	—	—	—	—	—	—
14	7.0066E-01	1.4783E+03	4.5894E-01	1.4785E+03	2.3554E-01	1.4787E+03	9.4289E-02	1.4789E+03	2.5457E-02	1.4790E+03	9.3469E-03	1.4790E+03	—	—	—	—
15	8.7881E-01	1.8146E+03	6.7030E-01	1.8148E+03	4.0766E-01	1.8151E+03	2.0028E-01	1.8153E+03	8.0476E-02	1.8154E+03	2.1900E-02	1.8155E+03	3.6194E-03	1.8155E+03	—	—
16	8.4261E-01	1.6513E+03	6.1509E-01	1.6515E+03	4.9179E-01	1.6516E+03	2.5599E-01	1.6519E+03	1.3122E-01	1.6520E+03	5.1872E-02	1.6521E+03	1.4263E-02	1.6521E+03	7.3465E-02	1.6520E+03

Table 9-12. Estimated alpha factor mean values for the 2015 generic priors [12].

Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9	α_{10}	α_{11}	α_{12}	α_{13}	α_{14}	α_{15}	α_{16}
2	0.9795	2.05E-02	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	0.9809	1.44E-02	4.68E-03	—	—	—	—	—	—	—	—	—	—	—	—	—
4	0.9795	1.36E-02	4.35E-03	2.50E-03	—	—	—	—	—	—	—	—	—	—	—	—
5	0.9823	9.90E-03	5.40E-03	1.97E-03	3.95E-04	—	—	—	—	—	—	—	—	—	—	—
6	0.9833	7.43E-03	5.27E-03	2.60E-03	9.65E-04	4.79E-04	—	—	—	—	—	—	—	—	—	—
7	0.9848	5.94E-03	4.32E-03	2.87E-03	1.50E-03	5.07E-04	9.22E-05	—	—	—	—	—	—	—	—	—
8	0.9855	5.10E-03	3.51E-03	2.68E-03	1.78E-03	8.84E-04	2.72E-04	2.39E-04	—	—	—	—	—	—	—	—
9	0.9865	4.51E-03	2.95E-03	2.42E-03	1.77E-03	1.11E-03	5.47E-04	1.59E-04	2.26E-05	—	—	—	—	—	—	—
10	0.9872	4.08E-03	2.55E-03	2.12E-03	1.69E-03	1.19E-03	7.27E-04	3.45E-04	9.53E-05	1.39E-05	—	—	—	—	—	—
11	0.9877	3.76E-03	2.26E-03	1.86E-03	1.56E-03	1.20E-03	8.20E-04	4.90E-04	2.21E-04	5.91E-05	3.12E-05	—	—	—	—	—
12	0.9882	3.51E-03	2.02E-03	1.66E-03	1.40E-03	1.17E-03	8.58E-04	5.82E-04	3.36E-04	1.43E-04	3.79E-05	3.86E-05	—	—	—	—
13	0.9888	3.23E-03	1.88E-03	1.48E-03	1.26E-03	1.10E-03	8.71E-04	6.25E-04	4.24E-04	2.31E-04	9.44E-05	2.51E-05	4.03E-06	—	—	—
14	0.9892	2.99E-03	1.76E-03	1.34E-03	1.14E-03	1.00E-03	8.77E-04	6.35E-04	4.74E-04	3.10E-04	1.59E-04	6.38E-05	1.72E-05	6.32E-06	—	—
15	0.9896	2.80E-03	1.66E-03	1.23E-03	1.03E-03	9.24E-04	8.20E-04	6.63E-04	4.84E-04	3.69E-04	2.25E-04	1.10E-04	4.43E-05	1.21E-05	1.99E-06	—
16	0.9899	2.63E-03	1.57E-03	1.15E-03	9.39E-04	8.47E-04	7.65E-04	6.54E-04	5.10E-04	3.72E-04	2.98E-04	1.55E-04	7.94E-05	3.14E-05	8.63E-06	4.45E-05

Table 9-13. Comparison of alpha factor mean values in both the component-specific CCF priors and the 2015 generic CCF priors.

Group Size	Alpha Factor	2015 Generic Priors (Reference [12])	2015 Pump Priors (Section 3)		2015 Valve Priors (Section 4)		2015 Strainer Priors (Section 5)		2015 Generator Priors (Section 6)		2015 Other Priors (Section 7)	
		Mean	Mean	Delta	Mean	Delta	Mean	Delta	Mean	Delta	Mean	Delta
2	α_2	2.05E-02	1.12E-02	-45%	3.54E-02	73%	9.69E-02	373%	7.92E-03	-61%	9.32E-03	-55%
3	α_2	1.44E-02	8.57E-03	-40%	2.69E-02	87%	5.06E-02	251%	5.17E-03	-64%	6.69E-03	-54%
	α_3	4.68E-03	2.00E-03	-57%	6.52E-03	39%	2.20E-02	370%	2.16E-03	-54%	1.20E-03	-74%
4	α_2	1.36E-02	7.97E-03	-41%	2.36E-02	74%	4.89E-02	260%	4.02E-03	-70%	7.33E-03	-46%
	α_3	4.35E-03	2.35E-03	-46%	9.04E-03	108%	1.73E-02	298%	2.10E-03	-52%	1.10E-03	-75%
	α_4	2.50E-03	9.46E-04	-62%	3.00E-03	20%	9.88E-03	295%	8.02E-04	-68%	1.56E-03	-38%

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APPENDIX A
BACKGROUND ON DIRICHLET DISTRIBUTIONS

The alpha factors of the same CCCG all have their own beta distributions but are bounded under the same Dirichlet distribution to ensure that, when sampling from each beta distribution, the sampled alpha factor values always add up to one. This appendix gathers writeups by C. Atwood to provide information on the mathematical background of Dirichlet distributions and to explore how an appropriate noninformative Dirichlet distribution can be determined. It also includes a section on generating random samples from a Dirichlet distribution, and examines an example case in detail.

A.1 DETERMINING AN APPROPRIATELY NONINFORMATIVE DIRICHLET DISTRIBUTION

The idea behind a noninformative prior is that it does not much affect the outcome. The Jeffreys prior for a binomial probability acts as if there were very few failures in very few trials: 1/2 a failure in 1 trial, to be exact. This behaves well if a moderate number of failures have been observed. But if no failures have been observed, 1/2 a failure might not be considered "very few." The Jeffreys prior then biases the results upward. To adjust for this, the idea of a constrained noninformative prior has come to be used, and is centered on some known mean but has a large variance. This idea runs into trouble with CCFs, because some failures are so rare that it is difficult to call any value "known."

In the common-cause setting, the mathematical structure is as follows. For $i = 1$ to m, the number of occurrences of events with i failed components is counted. Denote these counts by n_1, n_2, …, and n_m, with total n_{tot}. (Unlike the main report, n_1 is used here to include both independent failures and CCFs in which exactly one component failed.) In the present context, these are considered "prior data," used to construct a prior distribution for later plant-specific studies. Let α_i be the long-term fraction of failure events that have exactly i failed components. Then, the MLE of each α_i is n_i/n_{tot}. To get a Bayesian distribution for α_i, we consider all the α_is together and find the joint distribution that satisfies the condition $\Sigma\alpha_i = 1$. The distribution of $(\alpha_1, \ldots, \alpha_m)$ that corresponds naturally to the data is the conjugate distribution, Dirichlet$(\theta_1, \ldots, \theta_m)$. In the example of pumps, θ_i is provisionally estimated based on the data value n_i from Table 3-4. If $(\alpha_1, \ldots, \alpha_m)$ has this Dirichlet distribution, then each α_i has a beta$(\theta_i, \theta_{tot} - \theta_i)$ distribution. The mean and variance of α_i are:

$$\mu_i = \theta_i/(\theta_{tot} - \theta_i) \tag{A-1}$$

$$\sigma_i^2 = \mu_i(1-\mu_i) / (\theta_{tot} + 1) \tag{A-2}$$

When the value of θ_{tot} is large, the Dirichlet distribution has a small variance, and each α_i is known with great precision. If we want to make the distribution less informative (e.g., like a constrained noninformative prior), one natural way would be to reduce all the θ values by some common factor. Then the mean of the Dirichlet distribution would be unchanged, but the variance would increase.

This approach has trouble with multiple failures in large groups, as such failures are extremely rare. In Table 3-4 of the report, failure counts were inferred by mapping from CCF groups of various sizes. Mapping down has a justifiable logic to it, but mapping up is much more questionable, relying on the binomial failure rate (BFR) model. (One might ask, "If the BFR model can be relied on, why not use it throughout, instead of the alpha-factor model?") Moreover, the BFR model has a parameter ρ that must be estimated based on failure events in CCCGs of size ≥ 3; the pump data have only 30 such events. If we construct a "constrained noninformative" beta distribution for some very small α_i, we may have gone far beyond what can be reasonably done with a dataset containing so few CCF events. For example, consider the case of a complete CCF in a CCCG of size 8. (By the way, no complete CCF events actually exist in the data for CCCGs of size > 3.) Table 3-4 shows 0.163 such failures in 4813.12 failure events, giving an estimated alpha factor of 3.387E-5. This is not a "known" value for a prior mean; it may have a large relative error. But it is the best we can do.

Therefore, every proposal below uses the values built in Table 3-5 from the counts in Table 3-4—or close approximations to them—as the means for the alpha factors. These proposals are summarized here in Table A-1. The first line takes the adjusted counts in Table 3-4 and sets them to θ_1–θ_m. The resulting θ_{tot} is very large.

Table A-1. Various choices of θ to obtain a constrained, somewhat noninformative prior.

	θ_{tot}	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8
Table 3-4	4813.12	4774.93	12.952	10.004	7.551	4.573	2.225	0.722	0.163
CalcPrior	875	868	2.35	1.82	1.37	0.831	0.405	0.131	0.0296
Min. inf. Dirichlet	73.8879	73.3039	0.1985	0.1532	0.1156	6.99E-2	3.38E-2	1.08E-2	2.20E-3

CalcPrior had the effect of multiplying each element of this "Table 3-4" row by approximately 0.1818, yielding the values shown in the second row of Table A-1. The basis of this adjustment is unknown. CalcPrior is now being thoroughly revised for future calculations and will adopt a different method, proposed in [18], referred to as a "minimally informative Dirichlet distribution." It begins with the estimates based on Table 3-4 (see the first row of Table A-1) and then finds the mean of each α_i by applying Eq. (A.1). In [18], this mean is called the specified mean, $\mu_{spec,i}$. It next finds the (simplified) CNID for each separate α_i, constrained by the mean just found. Each such distribution is beta(a_i, b_i), with the parameters given by:

$a_i = 0.5$, $b_i = 0.5(1 - \mu_{spec,i})/\ \mu_{spec,i}$ if $\mu_{spec,i} < 0.5$

$b_i = 0.5$, $a_i = 0.5\mu_{spec,i}/(1 - \mu_{spec,i})$ if $\mu_{spec,i} > 0.5$

Based on these parameters, it finds the desired variance of each alpha factor, $\sigma^2_{spec,i}$. No Dirichlet distribution has this exact mean and variance for all the α_is. The method in [18] is to determine a Dirichlet distribution that is "close." More precisely, for estimated θ_i values, we find the estimated mean and variance by using Eqs. (A.1) and (A.2), and denote them as $\mu_{est,i}$ and $\sigma^2_{est,i}$. We then iterate on values of $\theta_1, \ldots, \theta_m$ to minimize:

$$\sum_{i=1}^{m} (\mu_{spec,i} - \mu_{est,i})^2 + (\sigma^2_{spec,i} - \sigma^2_{est,i})^2 \tag{A-3}$$

The results in row 3 of Table A-1 were found in this way. Observe that the distribution has a much smaller θ_{tot} than that in the other rows of Table 3-6. Therefore, this prior is much more diffuse.

Because the minimally informative Dirichlet prior has a known theoretical basis and can be implemented at INL, it is used as a suitable generic Dirichlet distribution.

A.2 Detailed Examination of an Example from Table 3-5, Row 8 of the Report

A.2.1 The Minimally Informative Dirichlet Prior

This example uses the data found in Table 3-5, row 8 of this report. In Table A-2 below, the mean alphas for the eight possible numbers of failures are taken as basic—or "specified," in the language of [18]. The CNIDs possessing those means are beta(a, b). The formulas used in [18] are as follows:

a = 0.5 b = 0.5*(1 – mean)/mean if mean < 0.5

b = 0.5 a = 0.5*mean/(1 – mean) if mean > 0.5

The variance of this CNID is mean*(1-mean)/(a + b + 1). In [18], this is referred to as the "specified" variance. These values are all shown in Table A-2.

Table A-2. Individual CNIDs matching means from data found in Table 3-5, row 8, for a CCCG size of 8.

Num. fails	1	2	3	4	5	6	7	8
Spec. mean	0.99210	0.00269	0.00208	0.00157	0.00095	0.00046	0.00015	0.00003
CNID a	62.7562	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CNID b	0.5	185.6099	240.6246	319.0588	528.1386	1090.979	3427.804	16814.78
Spec. var	0.000122	1.43E-05	8.56E-06	4.89E-06	1.79E-06	4.23E-07	4.37E-08	2.01E-09

No possible Dirichlet distribution has all these means and variances. This is because, in a Dirichlet distribution, every column in the table would have (a + b) equal the same total. Therefore, the minimally informative Dirichlet distribution is a compromise: a Dirichlet distribution that has *approximately* the same means and variances as specified in the above table. Specifically, consider a Dirichlet($\theta_1, \ldots, \theta_8$) distribution. Define $\theta_{tot} = \theta_1 + \ldots + \theta_8$. The beta($a_k$, b_k) distribution corresponding to the *k*th column in the table has $a_i = \theta_i$ and $b_i = \theta_{tot} - \theta_i$. The mean and variance can then be calculated from Eqs. (A.1) and (A.2). The minimally informative Dirichlet parameters are found by the optimizing software and are given in Table A-3 as "estimates." They are the values that minimize the sums of squared differences in Expression (A.3) above.

Table A-3. Minimally informative Dirichlet($\theta_1, \ldots, \theta_8$) distribution.

Num. fails	1	2	3	4	5	6	7	8
$\theta_i = a_i$	73.30389	0.19851	0.15322	0.11561	0.06989	0.03385	0.01078	0.00220
$\theta_{tot} - a_i = b_i$	0.58404	73.68942	73.73471	73.77231	73.81804	73.85408	73.87715	73.88573
Est. mean	0.99210	0.00269	0.00207	0.00156	0.00095	0.00046	0.00015	0.00003
Est. var	0.000105	3.58E-05	2.76E-05	2.09E-05	1.26E-05	6.11E-06	1.95E-06	3.97E-07

Note that the estimated means are almost identical to the specified means. The estimated variances may differ from the specified variances by up to two orders of magnitude, but are so small that they contribute very little to Expression (A.3). As for a and b, note that b_1 is somewhat larger than the specified 0.5; for $i > 1$, a_i is somewhat smaller than the specified 0.5.

A.2.2 Combining Alpha Factors

The minimally informative Dirichlet prior was developed via a complicated process involving the mapping of actual failure events and the numerical minimization of a sum of squares. However, the resulting distribution is interpreted in a simple way, as if we had observed θ_{tot} prior failure events. These events are classified as different types—in the example, the *i*th type is an event with exactly *i* failed components, for an *i* of 1 to 8 . These types of events occur following independent Poisson processes, and we interpret θ_i as the observed prior number of events of the *i*th type. This determines the prior distribution for each α_i, a beta(a_i, b_i) distribution, with a_i and b_i being determined by the formulas in the leftmost column of Table A-3.

Now consider some combination of types. For example, suppose we consider the long-term fraction of events with five or more failed components. This fraction is the sum $\alpha_5 + \ldots + \alpha_8$. The prior observed number of such events is $\theta_5 + \ldots + \theta_8$. We treat these sums as single parameters, denoted α_Σ and θ_Σ. That is, we combine the group of types into a single coarser type. This puts us back in the single-parameter situation, with θ_Σ prior events of interest and θ_{tot} prior events in all. The prior distribution of α_Σ is beta(a, b), with $a = \theta_\Sigma$ and $b = \theta_{tot} - \theta_\Sigma$.

Here, this is carried out in regard to the example of Table A-3. Table A-4 shows the individual beta distributions of each α_i when the joint distribution is given by the minimally informative Dirichlet distribution tabulated in Table A-3.

Table A-4. Beta distribution for each alpha factor, based on Table A-3.

redundancy *i*	θ_i	θ_{tot}	a_i	b_i	mean	var	sd/mean
2	0.19851	73.88793	0.19851	73.68942	0.002687	3.5779E-05	2.2264
3	0.15322	73.88793	0.15322	73.73471	0.002074	2.7633E-05	2.5350
4	0.11561	73.88793	0.11561	73.77232	0.001565	2.0861E-05	2.9191
5	0.06989	73.88793	0.06989	73.81804	0.000946	1.2619E-05	3.7555
6	0.03385	73.88793	0.03385	73.85408	0.000458	6.1147E-06	5.3976
7	0.01078	73.88793	0.01078	73.87715	0.000146	1.9479E-06	9.5662
8	0.00220	73.88793	0.00220	73.88573	2.98E-05	3.9758E-07	21.1769

Here, θ_{tot} is calculated by adding the first two numbers in column 1 of Table A-3. It is forced to be the same throughout Table A-4, though this number is slightly inaccurate due to the rounding off of the final digit. The values of parameters a and b are found using the formulas on the left of Table A-3, and the mean and variance are those of a beta(a, b) distribution.

The means shown agree with the values given in Table A-3, except perhaps for the rounding-off differences in the final digit. The variances are also shown. For skewed distributions such as these, it is also sometimes interesting to consider the relative standard deviation (i.e., the coefficient of variation), defined as (standard deviation)/mean. This is shown in the final column of Table A-4.

Now let us find the distribution of $\alpha_\Sigma = \alpha_5 + \ldots + \alpha_8$. The first row of Table A-5 shows θ_Σ, obtained as the sum of the values of θ_i in rows 5–8 of Table A-4. The usual calculations are carried out in the other columns of Table A-5, giving the mean and variance of α_Σ.

Table A-5. Beta distributions of selected sums of alpha factors, based on Dirichlet distribution.

Sum of interest	θ_Σ	θ_{Tot}	a	b	mean	var	sd/mean
5-8	0.11672	73.88793	0.11672	73.77121	0.00158	2.1061E-05	2.9051
2-8	0.58406	73.88793	0.58406	73.30387	0.007905	1.0472E-04	1.2946

As a second example, let us consider the fraction of events with multiple failed components, $\alpha_\Sigma = \alpha_2 + \ldots + \alpha_8$. This is shown in the second row of Table A-5. Because the fraction of events with multiple failed components is 1 minus the fraction of single failures, we compare the distribution in Table A-5 with that of α_1 in Table A-3. We see that, except for the round-off error in the final digits, a and b in Table A-5 equal b and a in column 1 of Table A-3—the same values but in reversed positions, as expected.

This concludes the example calculations using the Dirichlet distribution. Now let us compare them to the corresponding calculations in which the individual alpha factors are assumed to have independent beta distributions. This can be confusing, so let us repeat the basics here. Individually, each α_ks has a beta distribution, as shown in Table A-4. Now consider their *joint* distribution. Because the sum of α_1 through α_8 must equal 1.0, the individual α_is are not independent of each other; for example, if one α_i is larger than its mean, that pushes the other α values to be smaller. This negative correlation is modeled by the joint Dirichlet distribution, but is ignored if the α_is are treated as being statistically independent.

In the example of $\alpha_5 + \ldots + \alpha_8$, the mean is the same regardless of which joint distribution is used. If the joint distribution is Dirichlet, the distribution of the sum is found by summing the corresponding θ_is in Table A-4 and following the formulas for Dirichlet, as shown in Table A-5. If instead, the joint distribution treats the α_is as independent, the variance of the sum is the sum of the corresponding variances in Table A-4. The values for the two examples are compared in Table A-6.

Table A-6. Means and variances of the sum of the alpha factors, using two assumed joint distributions.

Sum of interest	mean		variance	
	Dirichlet	Indep. Betas	Dirichlet	Indep. Betas
5-8	0.001580	0.001580	2.1061E-05	2.1079E-05
2-8	0.007905	0.007905	1.0472E-04	1.0535E-04

The two methods give the same means—as they must, because the mean of a sum is the sum of the means regardless of whether the terms are independent or not. The Dirichlet distribution gives a slightly smaller variance than the variance when the alpha factors are assumed to have independent beta distributions. However, these differences are very small in these examples: less than 1%. In short, for alpha factors it is not clear that the method used makes any practical difference.

A.3 Generating Random Samples from a Dirichlet Distribution

At some part of a PRA, suppose that the Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE) uses alpha factors ($\alpha_1, \ldots, \alpha_m$), and that these alpha factors have a Dirichlet($\theta_1, \ldots, \theta_m$) distribution for their uncertainties. In the PRA, various values of the vector ($\alpha_1, \ldots, \alpha_m$) must be generated from this uncertainty distribution. This turns out to be easy. (One reference is Wikipedia: Dirichlet distribution, Section 5.1.1.)

For a Dirichlet($\theta_1, \ldots, \theta_m$) distribution, let y_1–y_m be independently sampled from m gamma(θ_i, 1) distributions. Define y_{tot} as the sum of $y_1 + \ldots + y_m$. Set $\alpha_i = y_i/y_{tot}$ for each i. Then, ($\alpha_1, \ldots, \alpha_m$) is a sample from a Dirichlet($\theta_1, \ldots, \theta_m$) distribution.

By the way, if $m = 2$, the Dirichlet distribution is a beta distribution, and the sampling method works in this case to generate values from a beta distribution. Also, the gamma distributions do not need to have the second parameter equal 1; that parameter is a scale parameter, and any value can be used as long as it is used consistently for every y_i.