Sodium Valve Performance in the NaSCoRD Database

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Abstract: Sodium Fast Reactors (SFRs) have an extensive operational history that can be leveraged to accelerate the licensing process for modern designs. Sandia National Laboratories (SNL) has recently reconstituted the United States SFR data from the Centralized Reliability Database Organization (CREDO) into a new modern database called the Sodium (Na) System Component Reliability Database (NaSCoRD). This new database is currently undergoing validation and usability testing to better understand the strengths and limitations of this historical data. The most common class of equipment found in the NaSCoRD database are valves. NaSCoRD contains a record of over 4,000 valves that have operated in EBR-II, FFTF, and test loops including those operated by Westinghouse and the Energy Technology Engineering Center. Valve failure events in NaSCoRD can be categorized by working fluid (e.g., sodium, water, gas), valve type (e.g., butterfly, check, throttle, block), failure mode (e.g., failure to open, failure to close, rupture), operating facility, operating temperature, or other user defined categories. Sodium valve reliability estimates will be presented in comparison to estimates provided in historical studies. The impacts of EG&G Idaho's suggested corrections and various prior distributions on these reliability estimates will also be presented.

Keywords: PRA, CREDO, NaSCoRD, Sodium, Valves.

1. INTRODUCTION

This paper records initial efforts at Sandia National Laboratories (SNL) to recreate the reliability analysis potential of the historical Centralized Reliability Database Organization (CREDO) database. A new database called the Sodium (Na) System Component Reliability Database (NaSCoRD) was created in 2017 using a portion of the original CREDO data supplemented with data from other historical records. This paper uses NaSCoRD to better understand the strengths and limitations of the retrieved CREDO data. Regaining these capabilities will allow the Department of Energy (DOE) complex and the United States (US) sodium-cooled fast reactor (SFR) industry to better understand how previous systems were designed and built. This information may be used to improve the design and operation of future systems by learning from history. Development of this database thus helps to address key knowledge management and preservation issues as identified in the multi-year study entitled SFR Safety and Licensing Research Plan, Ref. [1, p. 64].

With the loss of the CREDO database in the 1990s, the US lost a key record of historic system operation which could have been used to support future design studies and facility designs. The Japanese Atomic Energy Agency (JAEA) provided the US facility component of the CREDO database to the US in August of 2016. SNL, under DOE Advanced Reactor Technologies funding, has over the last year improved the current understanding of the quality, strengths, and limitations of this historical database. SNL has also developed an external user portal to allow third-parties to access the database [2].

NaSCoRD and its supporting data sources are diagrammed in Figure 1. The focus of this paper is the characterization of valve data from the portion of the CREDO database, designated CREDO-I in Figure 1, identify significant deviations from the original CREDO as Japanese reactor and test loop data have been removed from CREDO-I. CREDO-II represents an effort to retrieve historical reliability data from historical reports and run logs from US facilities. CREDO-II is used primarily for verification of CREDO-I data as these historical reports and logs did not generally contain design and/or reliability information such as the total number of and types of components. In the future, the data structures in NaSCoRD may be expanded to accommodate new facilities while retaining the ability to characterize historical facilities.

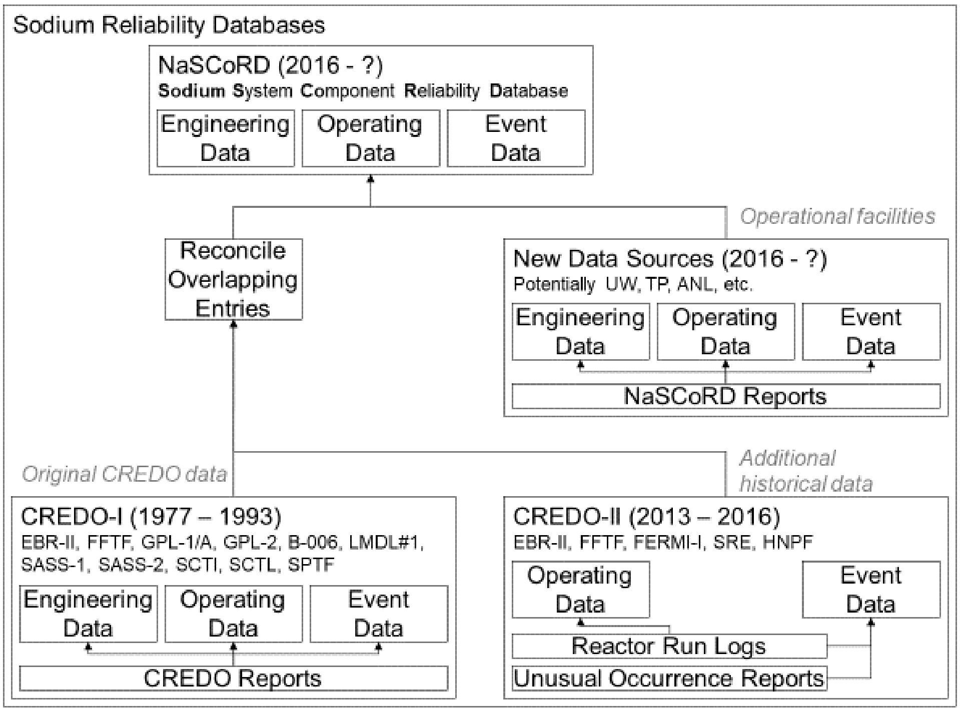

Figure 1: Diagram of Current and Anticipated NaSCoRD Data Sources

This paper evaluates the robustness of our current ability to estimate valve reliabilities from the NaSCoRD database:

- Section 2 discusses the methodology used in both previous reliability studies of the CREDO database and the current reliability studies conducted using NaSCoRD.

- Section 3 presents the results from a Bayesian reliability analysis with a focus on the relative impact of various priors as well as the impact of various segmentations of the data (e.g., valve type and failure mode).

- Section 4 discusses the difficulties in assessing the probabilities of valve failure-to-actuate given the current NaSCoRD data.

2. NaSCoRD VALVE RELIABILITY STUDY METHODOLOGY

Section 2 introduces the failure rate analysis:

- Section 2.1 will explain the purposes of the study as well as introduce some methodologies.
- Section 2.2 outlines the scope of the data that were used.
- Section 2.3 provides details of a Bayesian process used to analyze the data.

2.1 Motivation of Study

The differences in the historical contents of the CREDO database, including the historical Japanese facility data, and the current NaSCoRD contents may result in deviations of reliability insights. Regardless of whether these deviations are facility-dependent or simply a function of the size of the dataset, NaSCoRD developers need to compare the current data with similar historical reliability studies to quantify any deviations. A survey of historical valve studies performed based on CREDO data showed that many subcategories of valve data were studied including fluid temperatures, materials, working fluids, and failure modes. One of the most comprehensive analyses from the CREDO data was EG&G's Informal Report on reliability data for light water and sodium reactors [3]. Because the EG&G report presented failure rate estimates for multiple valve types across different failure modes, it was chosen as the primary comparison tool to assess the deviations between the NaSCoRD and CREDO data. A primary goal of this analysis is to perform similar analysis to that in EG&G [3] with similar prior assumptions while investigating the impact to the study's conclusions.

In addition to comparing the current and historical data sets, SNL is also interested in determining the robustness and accuracy the underlying historical CREDO data. The CREDO engineers had significant flexibility in reporting events through the CREDO system which may now translate into incorrectly reported events in the NaSCoRD. EG&G [3] conducted a comprehensive review of different failure events and modes within CREDO to determine if these events were applicable for PRA applications. EG&G provided a list of recommended changes to multiple events that could be reclassified or should be excluded from reliability calculations (e.g., a failure event may have been listed in CREDO that did not result in loss of component function). This paper will estimate failure rates for the NaSCoRD data both with and without the EG&G recommendations to provide insights regarding the sensitivity of failure rate estimations.

The reliability estimates will be tested with multiple sources of prior information. Informative prior distributions for valve failure rates are sourced from EG&G [3] as these represented the best estimates available at the time. While the CREDO data were used by EG&G in developing their reliability estimates, EG&G's goal was to provide reliability estimates for future power reactors and not the test facilities which comprised the CREDO database. As such, the component failure rates provided by EG&G are expected to be lower with higher uncertainties when compared to the rates calculated directly from the NaSCoRD data[*]. A non-informative prior distribution will also be applied to the NaSCoRD data to verify the impact of the EG&G sourced prior distributions which have the potential to be self-referential on the final reliability estimates.

This study will only focus on the failure-to-run failure mode. In both CREDO and NaSCoRD, both the hours that a valve is in operation and the number of demands made are estimated using the time the facility is in each operational mode and the subsequent conditional operational characteristic estimated by the installers of that valve. The hours of operation estimates are judged by the authors to be more reliable than the number of demands estimate. The issues related to estimating the number of demands will be discussed further in Section 4.

2.2 Scope of Study

This study uses all the US data that was included in the CREDO database that was gathered from 1979 to 1992 when the US and Japan stopped sharing sodium reactor reliability information. The NaSCoRD data contains operating information from 12 different units spanning from 1964 to 1992 with data prior to 1979 estimated from facility operational documents. The current NaSCoRD database does not contain any data from Japanese plants and test loops.

A primary challenge of estimating valve failure rates is defining clear component and failure mode boundaries. NaSCoRD has many categories for valve failures which has the benefit of adding detail to failure reports but can obscure direct comparisons to common risk assessment failure modes. While many reliability studies only consider a general failure rate, a survey of valve reliability studies shows some common failure modes which seem to be of the most interest. For example, Ref. [4] considers failure modes like those provided in Ref. [3, p.10]. These failure modes include internal seat leakage, external leakage, failure to move, plugging, and unspecified. The original CREDO developers provided a methodology for sorting their granulated failure modes into the more general PRA categories. One of the most comprehensive attempts to define these failure mode boundaries for the CREDO data can be

[*] It is common to assume that components used in a power reactor will have lower failure rates than similar components used in test reactors. Until proven, this assumption is compensated for by an increase in the estimated uncertainty associated with the failure rate.

found in Appendix A of Ref. [3], thus their recommended failure modes were used heavily in this analysis. Those failure modes included failure to move, spurious operation, plug, internal leakage, external leakage, internal rupture, and external rupture. Ref. [3] conducted their analysis on a wide range of valve types including manual, motor, hydraulic/pneumatic, solenoid, and check valves. The same valve classification was used in this study.

2.3 Methods

A Bayesian approach was used to estimate the failure rates of sodium valve failure modes and associated uncertainties. This facilitates accomplishing all the goals outlined in the introduction by using multiple sources of prior information to analyze and evaluate the data. The time until failure data were assumed to follow an exponential distribution which is a common assumption for failure rates in PRAs. This Bayesian updating process is illustrated in Figure 2.

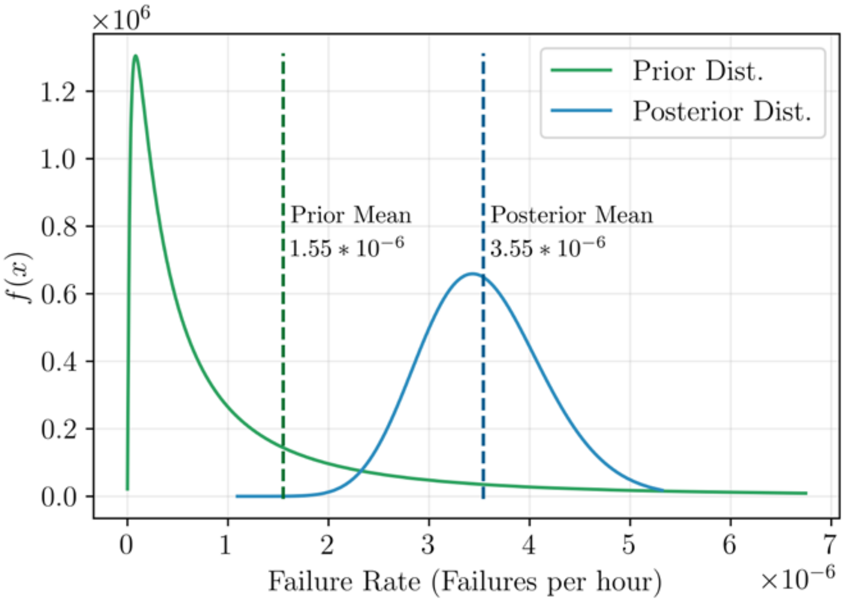

Figure 2: Example of a Bayesian Update from an EG&G informative prior to a posterior distribution for the total failure rate of motor valves.

2.3.1 Prior Distribution

Three prior distributions for failure-to-run valve failures were chosen to analyze the data:

1. An informative distribution was developed by using a lognormal distribution with a mean and error factor gathered from EG&G recommendations [3].
2. Another informative distribution was developed by using a lognormal distribution with a mean aggregated from outside sources referenced by EG&G combined with the error factors from EG&G as the outside sources did not provide uncertainties [3].
3. The non-informative prior was developed by assuming a Jeffreys prior [5] for the exponential distribution.

The uncertainties from EG&G were presented in the form of a lognormal distribution, shown in Eq. (1) [3]:

$$p(\lambda|\sigma^2, \mu) = \frac{1}{\lambda\sqrt{2\pi\sigma^2}} \exp\left(\frac{-(\ln\lambda - \mu)^2}{2\sigma^2}\right) \quad for\ \lambda > 0 \tag{1}$$

Where:

- $p(\lambda|\sigma,\mu)$ = The informed lognormally distributed prior distribution of λ given the lognormal parameters σ and μ
- λ = Valve failure rate (failures/hour)
- $\sigma^2 = \left(\frac{\ln(error\ factor)}{1.645}\right)^2$
- $\mu = \ln(expected\ failure\ rate) - \frac{\sigma^2}{2}$

Therefore, the same structure was retained for the two informative prior distributions. The parameters of the underlying distribution were taken from Ref. [3].

Lastly, a noninformative prior was used to see how much the data was affected by the above informative priors. Jeffreys prior for exponential data was used to model the prior knowledge on the failure rate in failures per hour. In this exponential case, the prior distribution follows a Gamma distribution, Eq. (2), with parameters $\alpha = 0$ and $\beta = 0$ [6, p.214].

$$p(\lambda|\alpha = 0, \beta = 0) = \frac{\beta^{\alpha}\lambda^{\alpha-1}e^{-\beta\lambda}}{\Gamma(\alpha)} = \lambda^{-1}\ for\ \lambda > 0 \tag{2}$$

Where:

- $p(\lambda|\alpha = 0, \beta = 0)$ = Jeffreys prior distribution of the failure rate λ
- α and β = Shape parameters of the gamma distribution
- $\Gamma(\alpha)$ = The gamma function evaluated at α

In addition to looking at multiple priors, the parallel analyses were performed on the data both in their original form and after making the recommended corrections to the underlying data [2, 3].

2.3.2 Sampling Distribution

The exponential distribution was chosen to evaluate the probability of experiencing a data set given a failure rate. Future work may incorporate other distributions to assess sensitivity. The primary reason why simplicity is preferred in this case is because there is a substantial proportion of the valve survival times that are censored. Two common reasons that a valve's failure time may be censored are:

1) A plant/test loop ended operations prior to the valve experiencing a failure or
2) The valve failed for a different reason and was then repaired or replaced.

In either of the above cases, the valve failure time and mode are not observed. It would not be appropriate to assume that the valve would never have failed, thus the failure must be inferred to occur at some time after the censored time. It is easier to take censored data into account with a memoryless distribution such as the exponential distribution than it is for other assumed distributions because the failure rate will remain constant regardless of how long the valve has survived [7, p.101]. With the exponential assumption, the sampling distribution is shown in Eq. (3):

$$f\left(\underline{y}\,\middle|\,\lambda\right) = \prod_{i=1}^{n}\left(\frac{1}{\lambda}\exp\left(\frac{y_i}{\lambda}\right)\right)\prod_{j=1}^{m}\left(\exp\left(\frac{y_j}{\lambda}\right)\right)\ for\ \lambda, y_i, y_j > 0 \tag{3}$$

Where:

- $f\left(\underline{y}\,\middle|\,\lambda\right)$ = the sampling distribution for the data vector $\underline{y}$ given the failure rate λ
- $\underline{y}$ = A vector of observed times until failure/censorship
- n = Number of uncensored observations
- m = Number of censored observations

This sampling distribution can then be maximized with respect to λ to find the maximum likelihood estimate (MLE) of λ given the observed data [7, p.315].

Valve failure rates are often inferred through operation time and failure counts [8]. This data structure naturally suggests a Poisson [7, p.92] sampling distribution to model the failure event counts. Since the interval in-between Poisson events is exponentially distributed [7], NaSCoRD's failure rate estimation based on a valve's time until failure from the exponential distribution is equivalent to the rate of failures counts for a Poisson model (one that would account for event censoring). Since NaSCoRD data has sufficient information to calculate the time until a valve's failure, times until failure was used instead of failure counts to facilitate future analysis. As mentioned, future work can consider other sampling distributions in which the failure rate is not believed to be constant over time, which would violate Poisson assumptions.

2.3.3 Posterior Distribution

The information from the prior distribution and the distribution of the data are combined to form a posterior distribution that acts as a weighted average of the two distributions. This is accomplished using Bayes' Theorem:

$$p(\lambda \mid \underline{y}) \propto f\left(\underline{y} \,\middle|\, \lambda\right) p(\lambda) \tag{4}$$

Where:

- $p(\lambda \mid \underline{y})$ = Posterior distribution of the failure rate given after incorporating the data vector $\underline{y}$
- $p(\lambda)$ = Prior distribution of the failure rate

Although the product of the prior and the sampling distribution is only proportional to the posterior distribution, the prior and the sampling distribution may be sampled from using Markov Chain Monte Carlo methods (or any other suitable simulation method) to produce inferences from the posterior distribution.

3 BAYESIAN RELIABILITY ANALYSIS OF SODIUM VALVES

Section 3 will discuss the reliability analysis for sodium valves:

- Section 3.1 will discuss the sources of the underlying parameters of the prior distributions.
- Section 3.2 will discuss the results of the posterior update of the prior distributions.

3.1 Prior Distribution Definitions

The three prior distributions used in this analysis and referenced in Section 2.3.1 are defined in this section. The recommended prior distribution parameters are summarized in Table 1.

The first informative prior distribution used was based on recommended failure rates provided by EG&G [3]. Because their recommended failure rates were assumed to have a lognormal distribution, the same distribution was used as the prior distribution. EG&G also provided error factors for each estimate which are used to report the variance of an estimate. The error factor is defined as the ratio of the 5^{th} to the 95^{th} percentile of the lognormal distribution. These recommended failure rates were determined partially based on data extracted from CREDO. This approach has a potentially circular reasoning drawback in that some of the data that went into this prior distribution is also used in the likelihood estimation. The benefit to this approach is that it will allow the direct comparison of the failure rate estimate with the JAEA data and with the NaSCoRD data. The conservative estimates of the error factor should also allow the data to outweigh the impact of the prior provided the data is reasonably robust.

The second informative prior leverages historical sodium reactor risk assessment failure probabilities. EG&G [3] used the existing CREDO data but also reported other estimated rates gathered from many sources such as LMEC [9], LYON [10], CRBRP-4 [11], and GEFR 00554 [12]. These sources contain estimates that were made from 1970-1984. These sources contain failure rate information for specific slices of failure mode and valve type. Reported rates from these sources were aggregated to estimate underlying parameters of the prior distribution. However, these rates were presented as point estimates without associated uncertainties. EG&G recommended various error factors for each reported failure rate. The recommended error factors associated with a failure-to-run were assigned the value of 10. Because of this availability, it was convenient and appropriate to use a lognormal distribution for this historical information while using the EG&G recommended error factors of 10 as shown in Table 1.

Table 1: Prior Distributions for Sodium Valve Failure Rates (All rates in failures/hour)

Valve	Failure Mode	EG&G Recommended Prior Mean	Aggregated Prior Mean	Error Factor
Check	External Leakage	5.0E-07	5.7E-08	10
	Internal Leakage	5.0E-07	5.0E-07	10
	Plug	5.0E-07	5.0E-07	10
	Total	1.5E-06	1.1E-06	10
Hydraulic/Pneumatic	External Leakage	1.0E-06	2.8E-06	10
	Internal Leakage	1.0E-07	1.2E-04	10
	Plug	3.0E-08	1.2E-04	10
	Spurious Operation	3.0E-07	1.2E-04	10
	Total	1.4E-06	3.6E-04	10
Manual	External Leakage	3.0E-07	1.0E-08	10
	Internal Leakage	5.0E-08	1.0E-07	10
	Plug	5.0E-08	1.0E-07	10
	Total	4.0E-07	2.1E-07	10
Motor	External Leakage	5.0E-07	1.0E-05	10
	Internal Leakage	5.0E-07	1.0E-05	10
	Plug	5.0E-08	1.0E-05	10
	Spurious Operation	5.0E-07	1.0E-05	10
	Total	1.6E-06	4.0E-05	10
Solenoid	External Leakage	1.0E-06	2.8E-06	10
	Internal Leakage	1.0E-07	1.2E-04	10
	Plug	3.0E-08	1.2E-04	10
	Spurious Operation	3.0E-07	1.2E-04	10
	Total	1.4E-06	3.6E-04	10

3.2 Posterior Results

The posterior distribution is the result of normalized multiplication of the prior distribution by the probability of experiencing a dataset with respect to the parameter of interest. Section 3.2 discusses the posterior results in two sections:

- Section 3.2.1 discusses the sodium valve failure rates with all failure modes aggregated into the failure-to-run failure mode for all valve types.
- Section 3.2.2 divides the sodium valve failure rates into subcategories of failure modes.

3.2.1 Total Sodium Valve Failure Rates

To adequately understand the current state of the NaSCoRD database, the failure rates were first applied to the unaltered NaSCoRD data provided by JAEA. Once the unaltered database was examined for reasonableness and robustness to prior distribution assumptions, the data cleaning recommendations from SNL [2] and EG&G [3] were analyzed and compared to the unaltered database and the initial CREDO informed EG&G recommendations.

Before using the granularity of EG&G's failure modes, comparisons of general failures to run across different valve types were conducted to assess differences due to prior distributions and data classification. When considering the aggregate failure rates of diverse types of sodium valves, the failure rates were within 10% of each other despite any changes in the prior distribution or modifications to the data. Table 1 shows that for multiple valve types, such as motor, solenoid, and hydraulic/pneumatic, the prior expected failure rates varied significantly between the prior distributions. However, the same difference in magnitude did not appear in the posterior expected failure rate. This result suggests that there is enough data for each valve type to overwhelm the impact of a given prior distribution.

It is also important to determine how data cleaning recommendations affected failure rate estimates. The effect was generally even more negligible than the difference accounted for by the choice of prior. As can be seen in Figure 3, the failure rate that was affected the most by the data reclassification was with hydraulic/pneumatic valves. Even though some events associated with hydraulic/pneumatic valves were no longer considered, there were enough data that the maximum likelihood estimates only changed on the third significant digit. This resulted in minimal change in the estimated failure rate. Even though NaSCoRD's accuracy should be constantly improved through data cleaning recommendations, it appears that there is enough data such that overall failure rate data is robust against the small errors identified by EG&G.

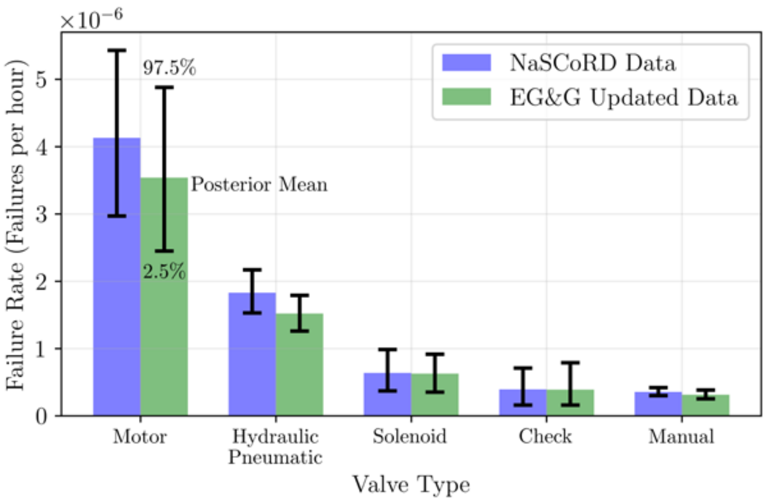

Figure 3: Posterior Sodium Valve Failure Rates with 95% Probability Intervals by Failure Modes (Rates based on EG&G prior).

Overall, the valves had similar failure rates which can be seen in Table 2. Motor and hydraulic/pneumatic had the highest failure rates at about $3.5 * 10^{-6}$ and $1.5 * 10^{-6}$ failures per hour. All other valve types had similar failure rates, all on the order of 10^{-7} failures per hour. Also, the variances of the estimates were similar enough such that the 97.5 and 2.5 percentiles had the same ordering from high to low as the posterior mean failure rates.

EG&G's [3] estimated failure rates were all on the order of 10^{-7} failures per hour with an error factor of 10. This suggests that the data cleaning estimates on US only data did not significantly change the information content of the NaSCoRD data from the initial CREDO data which included the JAEA data. This is beneficial to NaSCoRD data analysis because it allows for comparisons to prior work that included the JAEA data without the concern that the NaSCoRD data is not representative of prior knowledge of SFR valves.

Table 2: Sodium Valve Failure Rates for Other Failure Mode (All rates in failures/hour)

Valve	Failure Mode	EG&G Prior Mean	Evidence (Hours, Failures)	Posterior Mean	95% Probability Interval
Check	External Leakage	5.0E-07	(7.7E06, 2)	2.5E-07	(7.1E-08, 5.3E-07)
	Internal Leakage	5.0E-07	(7.7E06, 1)	1.5E-07	(3.4E-08, 4.3E-07)
	Plug	5.0E-07	(7.7E06, 0)	5.8E-08	(3.4E-09, 2.1E-07)
	Total	1.5E-06	(7.7E06, 3)	3.9E-07	(1.6E-07, 7.9E-07)
Hydraulic/ Pneumatic	External Leakage	1.0E-06	(1.6E07, 12)	7.0E-07	(5.4E-07, 8.7E-07)
	Internal Leakage	1.0E-07	(1.6E07, 1)	2.3E-07	(1.4E-07, 3.8E-07)
	Plug	3.0E-08	(1.6E07, 0)	6.0E-09	(3.9E-10, 1.4E-08)
	Spurious Operation	3.0E-07	(1.6E07, 6)	1.1E-07	(4.3E-08, 1.9E-07)
	Total	1.4E-06	(1.6E07, 21)	1.5E-06	(1.3E-06, 1.8E-06)
Manual	External Leakage	3.0E-07	(2.4E07, 3)	1.1E-07	(7.4E-08, 1.4E-07)
	Internal Leakage	5.0E-08	(2.4E07, 2)	5.9E-08	(3.6E-08, 8.2E-08)
	Plug	5.0E-08	(2.4E07, 2)	4.9E-08	(3.3E-08, 6.9E-08)
	Total	4.0E-07	(2.4E07, 9)	3.1E-07	(2.5E-07, 3.9E-07)
Motor	External Leakage	5.0E-07	(7.4E06, 2)	1.3E-07	(2.4E-08, 4.6E-07)
	Internal Leakage	5.0E-07	(7.4E06, 4)	4.8E-07	(1.8E-07, 9.4E-07)
	Plug	5.0E-08	(7.4E06, 1)	5.8E-08	(8.2E-09, 2.1E-07)
	Spurious Operation	5.0E-07	(7.4E06, 3)	1.4E-07	(1.2E-08, 4.3E-07)
	Total	1.6E-06	(7.4E06, 24)	3.5E-06	(2.5E-06, 4.9E-06)
Solenoid	External Leakage	1.0E-06	(4.7E06, 0)	6.0E-08	(2.7E-09, 1.9E-07)
	Internal Leakage	1.0E-07	(4.7E06, 2)	2.7E-07	(1.2E-07, 4.4E-07)
	Plug	3.0E-08	(4.7E06, 1)	4.3E-08	(1.6E-09, 1.2E-07)
	Spurious Operation	3.0E-07	(4.7E06, 0)	3.2E-08	(3.2E-09, 1.1E-07)
	Total	1.4E-06	(4.7E06, 3)	6.3E-07	(3.5E-07, 9.1E-07)

3.2.2 Sodium Valve Failure Rates for Sub-Category Failure Modes

The robustness of the estimated rates in section 3.2.1 could not be taken for granted when examining granular failure modes. EG&G divided the total failure rates into seven failure modes: failure to open/close, spurious operation, plug, internal leakage, external leakage, internal rupture, and external rupture. Using these failure mode bounds, there were no events in CREDO that would be classified as an internal or external rupture so they were left out of the analysis. Manual and check valves did not have the spurious operation failure mode because of the lack of a remote operator [3].

The problem of censoring outlined in section 2.3.2 is further compounded when considering competing failure modes. Since there are multiple competing failure modes that a valve can now experience, there is more chance to observe censored data.[†] Due to the higher likelihood of censored data and the lower likelihood of a specific event type when more granular failure modes are examined, the data may not be as robust to changes as it was when total failure rates were examined. In all valve type and failure mode combinations, the proportion of expected failure times that were censored was greater than 94% and sometimes as high as 98%.

Despite this high likelihood of censored survival intervals, the cleanup efforts did not strongly affect the posterior failure rates of the segregated failure modes. As mentioned in section 3.2.1, hydraulic/pneumatic valves were affected most by the recommended changes. When the valve type failure rates were further broken down into specific failure modes, the largest change was from $7.9 * 10^{-8}$ to $1.1 * 10^{-7}$ failures per hour. This suggests that the data cleaning did not significantly change the information content of the NaSCoRD data.

Even though inferences about granular failure rates do not appear to be sensitive to the changes above, the reduced total amount of data in the NaSCoRD data when compared to the CREDO data forces caution when looking at specific categories since there is a greater potential for insufficient failure data. In many of the valve type and failure mode combinations there were categories that had few to no recorded failure events. In these cases, the estimated rates were predictably sensitive to the choice of prior. The biggest impacts of the prior distribution occur when there were less than two observed events in a valve type and failure mode combination. The choice of prior dominated the posterior in nine instances. Most of the combinations were in the check valve and solenoid valve categories because there were one or fewer recorded failure events. Under the exponential distribution, zero recorded failures produce the maximum likelihood estimate of zero for the failure rate. Estimates of the failure rate based on a reference prior would then vastly underestimate the failure rates when compared to those based on informative priors. When studying specific failure modes, it is recommended that the analyst considers how many failures are present. A small number of failures may affect the reliability of the data.

4 SODIUM VALVE FAILURE-TO-ACTUATE FAILURE MODES

Failure rates associated with a valve failing to open or close are traditionally reported as a rate of failure per demand. Since the NaSCoRD database does not have actual demand data, it must be estimated. Each component has a duty factor which corresponds to the estimated number of demands per hour that may be made of the component while the reactor unit is in each state (power operations, hot standby, and cold shutdown). The NaSCoRD database does contain the number of hours each reactor was in each state in a quarterly period. Multiplying these two values gives an estimate for the number of demands in a quarter.

[†] For example, if a valve experiences an internal leak, the valve will likely be repaired or replaced. If monitoring the time until another failure mode, a plug for example, then the start time should reset to when it was repaired or replaced. Hence, the time prior to the repair would be censored with respect to the plug failure mode.

When conducting the analysis for this paper, it was discovered that some valves had a failure that was associated with a failure to move but had no estimated demands. In every case, this was because the duty factor given for the valve was zero for all reactor state categories. Of the seventy-five components with a failure to move, thirty-two of them had zero estimated demands. Because of this, per-demand failure rates may not be reliable.

One of NaSCoRD's immediate goals will be to improve and validate the demand estimations of the components. NaSCoRD contains all the information on when a valve was operational and when it may have failed. Further detail can be gathered through unstructured event narratives for each event. Searching specific operational logs along with the event narratives can be used to see if there is information on how many cycles a valve may have performed prior to the failure, something which is not a specific data field in NaSCoRD. If a valve does not have this information, it can possibly be grouped by factors such as system, subsystem, or valve type, among other factors. Duty factors could then be estimated based on data from similar valves. In the short term, failure rates based on a per-demand rate are not recommended to be calculated from NaSCoRD data.

5 CONCLUSIONS

The posterior failure rates for sodium fast reactor valves produced in this analysis were consistent with failure rates produced from the CREDO data prior to 1990. Many factors were tested that could have potentially changed inferences regarding the valve failure rates such as prior assumptions and cleaning recommendations from SNL and EG&G. Despite these differences, the inferred failure rates were consistent for each valve type and even the different failure modes within each valve type. This suggests that the current NaSCoRD data is robust not only to different reasonable prior assumptions but also slight changes due to data cleaning. In addition, the information lost due to the absence of the JAEA data does not seem to have changed the conclusions regarding average valve failure rates.

Prior assumptions had a greater impact when subdividing valve failure rates such as for specific failure modes within specific valve types. Certain subdivisions of data do not have enough observed failure data to overwhelm a diffuse prior distribution. Conclusions based off such data will not be as robust to different prior distributions.

Even though the data is generally robust, there remains work to be done to improve the accuracy, reliability, and infer-ability of the NaSCoRD data. This study has shown that valve demand estimation must be improved before similar reliability calculations can be performed when evaluating failure to move related failure modes.

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