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Creation of the NaSCoRD Database

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Creation of the NaSCoRD Database

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Abstract

This report was written as part of a United States Department of Energy (DOE), Office of Nuclear Energy, Advanced Reactor Technologies program funded project to re-create the capabilities of the legacy Centralized Reliability Database Organization (CREDO) database. The CREDO database provided a record of component design and performance documentation across various systems that used sodium as a working fluid. Regaining this capability will allow the DOE complex and the domestic sodium reactor industry to better understand how previous systems were designed and built for use in improving the design and operations of future loops. The contents of this report include: overview of the current state of domestic sodium reliability databases; summary of the ongoing effort to improve, understand, and process the CREDO information; summary of the initial efforts to develop a unified sodium reliability database called the Sodium System Component Reliability Database (NaSCoRD); and explain both how potential users can access the domestic sodium reliability databases and the type of information that can be accessed from these databases.

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Executive Summary

This document was written as part of a United States Department of Energy (DOE) Nuclear Energy (NE) Advanced Reactor Technologies (ART) program funded project, AT-17SN170208 SFR Database Development (CREDO) - SNL, to re-create the capabilities of the legacy Centralized Reliability Database Organization (CREDO) database. The CREDO database provided a record of component design and performance documentation across various systems that used sodium as a working fluid but was lost by its US custodian in the 1990s. Raw data of US origin was only recently recovered from the Japan Atomic Energy Agency (JAEA) with whom the US had established a joint database. This recovered version of CREDO is referred to as CREDO-I as it includes neither any JAEA facility data nor any of the original database relationships. This report records initial efforts at Sandia National Laboratories (SNL) to use the reconstructed CREDO data (CREDO-I) with reliability information sourced from operational documents, called CREDO-II, into a new modern database called the Sodium (Na) System and Component Reliability Database (NaSCoRD). Through this process the strengths and limitations of the data are characterized. CREDO originally included reliability data from the Experimental Breeder Reactor II (EBR-II), Fast Flux Test Facility (FFTF), and Joyo reactors and multiple non-nuclear test facilities. Regaining these capabilities will allow the DOE complex and the domestic sodium industry to understand how previous systems were designed and built and then use this information to improve the design and operations of future systems.

CREDO-I, CREDO-II, and Sodium System Component Reliability Database (NaSCoRD) will immediately benefit sodium system designers who can extract engineering, operational, and safety insights from these data sets. The ability to examine the failure modes for sodium components and the environments that led to multiple and repeated component failures will allow for future sodium loop and sodium reactor designers to leverage the expansive legacy of domestic sodium reactor operations. To allow the domestic sodium industry access to this data, Sandia has established a controlled access website for users to directly explore Structured Query Language (SQL) reports of the sodium reliability databases. The future expansion of NaSCoRD to new facility data sources provides the domestic industry with the best opportunity to develop a broad database to support future Probabilistic Risk Assessment (PRA) applications. Access to the sodium reliability database website shown in Figure 1 can currently be requested through the DOE-NE ART sodium reactor program manager. Access to the Sodium Reliability Database (SRD) website must comply with Sandia policies, procedures, and federal law.

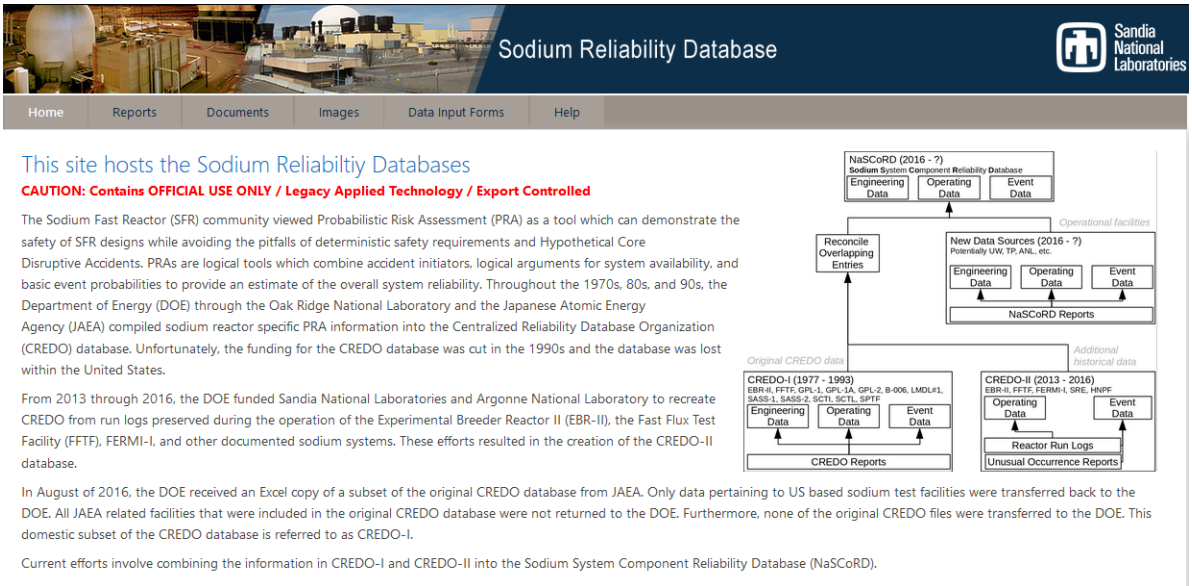


Figure 1: Screen-shot of the SRD Home Page

After analyzing the CREDO-I data for nearly a year it is clear that inconsistencies in the CREDO-I data make it difficult to use this information as-is to derive failure probabilities for PRA applications. Resolution of entry inconsistencies within CREDO will require a continued effort to identify, process, and extract corroborative information from operational logs, maintenance records, and unusual occurrence reports. One such inconsistency discussed in this report can be seen in Figure 2. Each operating data entry for EBR-II in CREDO-I accounts for approximately three months and for most entries the authorized power level was at or near the design power of 20 MWe. Because it was an experimental reactor, EBR-II commonly had periods with a low capacity factor, for example, to allow for old experiments to be removed and new ones to be set up. The number of hours in power operations for each period are plotted against the recorded output, with the line of 20 MWe in blue. Entries generally should not appear above the line, as that would suggest that during that time period the reactor averaged output above its design power level, which is unlikely for an experimental reactor. Fortunately, information from CREDO-II allowed the Sandia development team to confirm that the primary CREDO-I outlier entry was simply a factor of 10 higher than was actually recorded for this period. This example highlights the need for a significant data quality assurance process to reconcile inconsistencies for entries for which historical documentation is available and to explore the impact of entry inconsistencies for entries that cannot be reconciled.

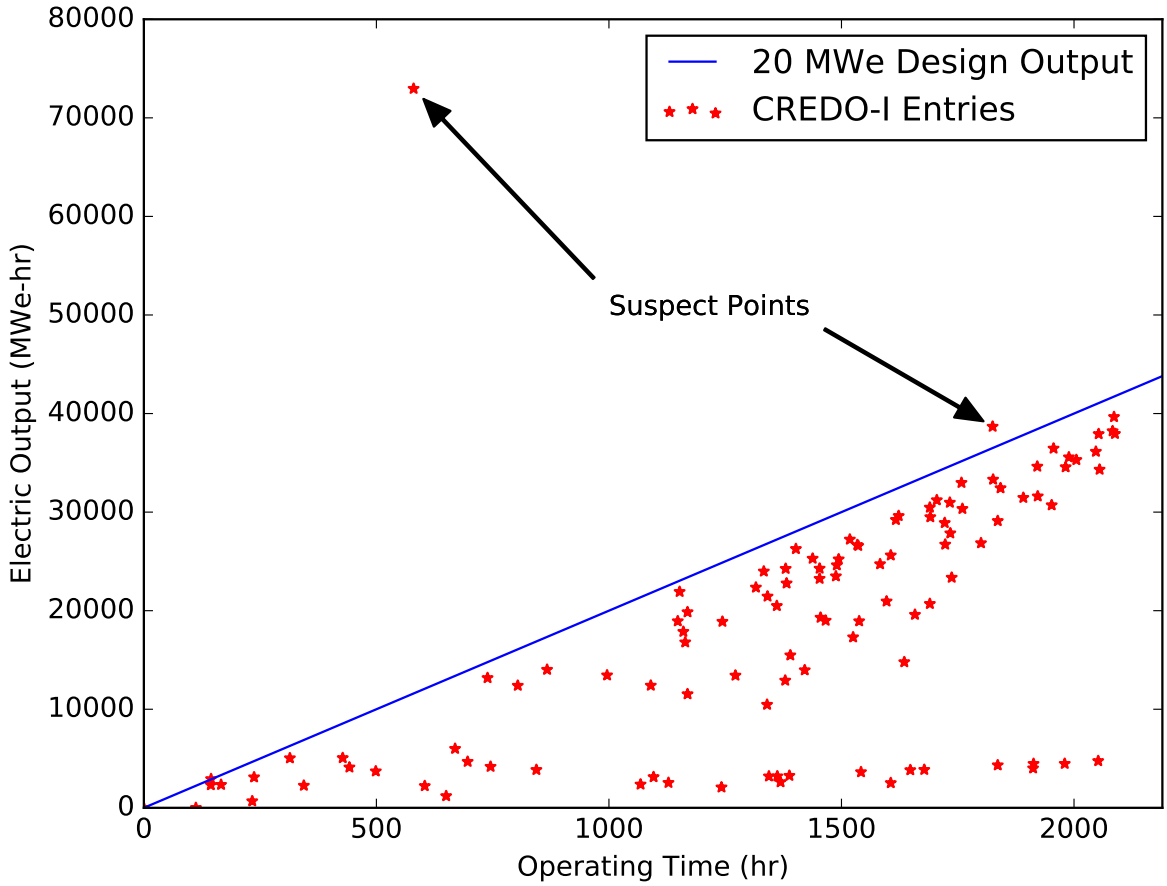


Figure 2: CREDO-I Outlier Detection, EBR-II Operating Data

Nomenclature

50MW SGTF 50MW Steam Generator Test Facility

AEC Atomic Energy Commission

ANL Argonne National Laboratory

ART Advanced Reactor Technologies

AT Applied Technology

CRDMTL Control Rod Drive Mechanism Test Loop

CREDO Centralized Reliability Database Organization

CRBR Clinch River Breeder Reactor

CRDM Control Rod Drive Mechanism

DOE United States Department of Energy

NE Office of Nuclear Energy

EBR-II Experimental Breeder Reactor II

ECN External Collaborative Network

ETEC Energy Technology Engineering Center

FREEDOM Fast Breeder Reactor Reliability Evaluation Database for Operation and Maintenance

FFTF Fast Flux Test Facility

GPL-1 General Purpose Loop 1

GPL-2 General Purpose Loop 2

HNPF Hallam Nuclear Power Facility

IHTS Intermediate Heat Transfer System

INL Idaho National Laboratory

JAEA Japan Atomic Energy Agency

LMDL#1 Liquid Metal Development Laboratory #1

LMEC Liquid Metal Engineering Center

LWR Light Water Reactor

NaSCoRD Sodium System Component Reliability Database

ORNL Oak Ridge National Laboratory

OSTI Office of Scientific and Technical Information

P&ID Piping and Instrumentation Diagram

PC Personal Computer

PNC Power Reactor Nuclear Fuel Development Corporation

PNNL Pacific Northwest National Laboratory

PRA Probabilistic Risk Assessment

PRISM Power Reactor Innovative Small Module

QA Quality Assurance

SASS Sodium Auxiliary Supply System

SCTF Sodium Chemistry Technology Facility

SCTL Small Component Test Loop

SCTI Sodium Components Test Installation

SEFOR Southwest Experimental Fast Oxide Reactor

SPTF Sodium Pump Test Facility

SFR Sodium-cooled Fast Reactor

SFTL Sodium Flow Test Loop

SNL Sandia National Laboratories

SQL Structured Query Language

SRD Sodium Reliability Database

SRE Sodium Reactor Experiment

TP TerraPower

UOR Unusual Occurrence Report

US United States of America

UW University of Wisconsin

WARD Westinghouse Advanced Reactors Division

1 Introduction

This document was written as part of a United States Department of Energy (DOE), Office of Nuclear Energy (NE) Advanced Reactor Technologies (ART) program funded project, AT-17SN170208 Sodium-cooled Fast Reactor (SFR) Database Development (CREDO) - SNL, M3AT-17SN1702081, to re-create the capabilities of the legacy Centralized Reliability Database Organization (CREDO) database [1, 2]. The CREDO database provided a record of component design and performance documentation across various systems that used sodium as a working fluid. However, CREDO was lost and a version of its raw data was only recently recovered.

This document records initial efforts at Sandia National Laboratories (SNL) to both reconstitute the CREDO data into a new modern database called the Sodium (Na) System Component Reliability Database (NaSCoRD) and better understand the strengths and limitations of this data. Regaining these capabilities will allow the DOE complex and the United States of America (US) SFR industry to better understand how previous systems were designed and built and use this information to improve the design and operations of future systems. Development of this database helps to address key knowledge management and preservation issues as identified in the multi-year study entitled SFR Safety and Licensing Research Plan [3, p. 64].

With the loss of the CREDO database in the 1990s, the US lost a key record of the historic system operated, which could have been used to support future design studies and facility designs. Supported by a renewed effort to construct a new reliability database over the past year, this document will:

- Provide the reader context regarding the current state of the US Sodium Reliability Databases (SRDs).
- Explain to users how they can access the US SRDs and the type of information that can be accessed from these databases.
- Describe the ongoing efforts to improve, understand, and process the CREDO data.
- Present the concept for a future unified SRD called Sodium System Component Reliability Database (NaSCoRD).
- Encourage sodium facility operators to both access and contribute to NaSCoRD.

This introduction section provides the following content:

- Section 1.1 provides a brief explanation of key terms used in this document.
- Section 1.2 outlines section progression of this document.
- Section 1.3 summarizes the history of SRDs in the US.
- Section 1.4 presents the present and future of US SRDs.

1.1 Document Terminology

A variety of terms are used throughout this document, in reference to historical databases as well as to the arrangement and access to the NaSCoRD database. These terms are listed and defined below:

- SRD: A generic term for a database which contains information related to sodium component reliabilities.
- LMEC-data: Failure data sourced from the 1970 Liquid Metal Engineering Center (LMEC) survey of sodium reactor component performance.
- CREDO: The sodium component reliability database project that was operated at Oak Ridge National Laboratory (ORNL) from approximately 1977 to 1993.
- CREDO-I: The partial copy of the CREDO database that SNL received from Japan Atomic Energy Agency (JAEA) in August of 2016 [4].
- CREDO-II: The database created from historical run logs and event documents. This SRD is less comprehensive than CREDO-I and is primarily used to validate CREDO-I records.
- NaSCoRD: The database created by merging entries from CREDO-I and CREDO-II.
- Report: A predetermined presentation of information from the underlying Structured Query Language (SQL) database.
- Record: A field within a report. Record names are denoted using the *emphasized* format in this report.
- Entry: A value within a record. Entry names are denoted using the SMALL CAPITALIZATION format in this report.
- Script: A script refers to python code, typically used for data exploration. Script names are denoted using the `typewriter` format in this report.
- File: A file refers to data saved as a Microsoft spreadsheet. File names are denoted using the *italic* format in this report.
- Document: A reference source of information.

1.2 Structure of the Document

The balance of this report is arranged as follows:

- Section 2 gives examples of statistical analysis that may be performed on the data.

- Section 3 documents quality assurance efforts related to the CREDO-I data.
- Section 4 presents the combination of CREDO-I and CREDO-II data into NaSCoRD.
- Section 5 describes the interface for external access to CREDO-I data.
- Section 6 summarizes the key findings and progress.
- Appendix A provides a preliminary sample system breakdown for Control Rod Drive Mechanisms (CRDMs)
- Appendix B gives preliminary examples of fields that the NaSCoRD input forms may include.

1.3 History of Sodium Reliability Databases

The first sodium system performance database was developed by LMEC [5, 6] in the 1960s and was intended to provide operational and design insights from the reactors and test loops of its day. The LMEC data was comprised primarily of new or experimental components. While failure rates for various components were reported, this database predated mainstream reactor Probabilistic Risk Assessments (PRAs) such as WASH-1400 [7] and thus was not structured with any associated requirements for such applications. In the late 1970s, the DOE funded ORNL to develop a component reliability database for SFRs [8, p. 101–114] with the explicit purpose of supporting PRA applications. During this time period, Clinch River Breeder Reactor (CRBR) used PRA to support its licensing efforts [9]. During the 1980s, the use of PRA to support the safety assessment of Power Reactor Innovative Small Module (PRISM) [10, Appendix A] and Experimental Breeder Reactor II (EBR-II) [11, 12] further highlighted the need for a robust PRA focused reliability database. Foreign reactors such as Monju also conducted PRAs, thus DOE entered a partnership with Power Reactor Nuclear Fuel Development Corporation (PNC), now JAEA, to combine the Fast Breeder Reactor Reliability Evaluation Database for Operation and Maintenance (FREEDOM) database with the CREDO database [13, p. 1-3]. It is the author's understanding that during the 1990s, the CREDO database was lost within the US as it was not transitioned from the ORNL mainframes onto Personal Computer (PC) databases [14].

CREDO included reliability data from the EBR-II, Fast Flux Test Facility (FFTF), and Joyo reactors, as well as test facilities at the Energy Technology Engineering Center (ETEC), Westinghouse Advanced Reactors Division (WARD), Control Rod Drive Mechanism Test Loop (CRDMTL), Sodium Flow Test Loop (SFTL), and the 50MW Steam Generator Test Facility (50MW SGTF) [13, p. 2]. A number of reliability studies were performed using the CREDO database, with a strong focus on valves [15, 16, 17].

1.4 Present and Future of Sodium Reliability Databases

Starting in 2014, parallel efforts were undertaken both to re-create a sodium reliability database sourced from historical documents and retrieve a copy of the ORNL-era CREDO data. The new data gathering effort created a database which is referred to as CREDO-II and the scope of this SRD was extended to facilities that were not originally included in CREDO, such as Fermi-I, Hallam Nuclear Power Facility (HNPF), and the Sodium Reactor Experiment (SRE). After a partial, US facility only, copy of the original CREDO database was obtained (referred hereafter as CREDO-I) from JAEA [4] in unformatted spreadsheets, efforts shifted to both merging the two databases and providing analysis tools to query the data. The combined data set is referred to as NaSCoRD and a diagram of the data sources is given in Figure 3. Previously-undefined terms in Figure 3 include: Sodium Auxiliary Supply System (SASS), University of Wisconsin (UW), TerraPower (TP), General Purpose Loop 1 (GPL-1), and General Purpose Loop 2 (GPL-2).

The majority of the existing data in NaSCoRD comes from merging the CREDO-I and CREDO-II SRDs. Only CREDO-I contained engineering design information and only CREDO-II contained daily operational records. As discussed in Sections 3 and 4, data validation and quality assurance efforts were undertaken when data overlap existed between the CREDO-I and CREDO-II data. Tools were developed to identify common failure events for proper handling in NaSCoRD as well as to reconcile operating information that was provided on a quarterly, monthly, daily, or run-based basis. In addition to the existing data, NaSCoRD is intended to accept data that exists in neither CREDO-I nor CREDO-II. This is represented by the *New Data Sources* field in Figure 3 and is expected to include currently-operating sodium test loops.

The reactors that are expected to be included in NaSCoRD are presented in Table 1 along with some defining characteristics. This may expand if either international data is secured or new domestic facilities are incorporated. The test facilities for which NaSCoRD currently has data are given in Table 2. This is likely to expand as NaSCoRD input capabilities are developed (see Section 5.2.5).

In recent years there have been numerous independent efforts within the DOE national laboratories to gather and analyze sodium component reliability data, but these efforts have had limited success without access to CREDO-I. An Idaho National Laboratory (INL) paper reviewed the various sources, including published CREDO documents, to bound failure rates for liquid metal cooling system components [18] but did not have access to engineering records. An effort at Pacific Northwest National Laboratory (PNNL) sought to locate the FFTF CREDO input forms in order to recreate a portion of the database for use in developing a time-dependent reliability evaluation methodology [19], but PNNL was not able to recover enough information to create a database. Finally, a recent effort at Argonne National Laboratory (ANL) generated a composite sodium component reliability database from a variety of sources with the results compared to those gathered from papers related to the CREDO database [20]. It is expected that each of these efforts will be enhanced by having access to the CREDO-I information.

Table 1: Reactors Slated for Inclusion in NaSCoRD
Previously-undefined term: Southwest Experimental Fast Oxide Reactor (SEFOR)

Facility	Location	Thermal Power (MWt)	Design	Criticality Year
EBR-II	Idaho	62.5	Pool	1963
FFTF	Washington	400	Loop	1980
Fermi-I	Michigan	200	Loop	1963
SEFOR	Arkansas	20	Loop	1969
SRE	California	20	Loop	1957
HNPF	Nebraska	240	Loop	1963

Table 2: Test Facilities Currently Included in NaSCoRD
Previously-undefined term: Liquid Metal Development Laboratory #1 (LMDL#1)

Facility	Operator	First Record
SCTI	ETEC	1978
SCTL	ETEC	1971
SPTF	ETEC	1975
B-006	ETEC	1990
LMDL#1	ETEC	1975
GPL-1/A	WARD	1967
GPL-2	WARD	1971
SASS-1	WARD	1978
SASS-2	WARD	1978

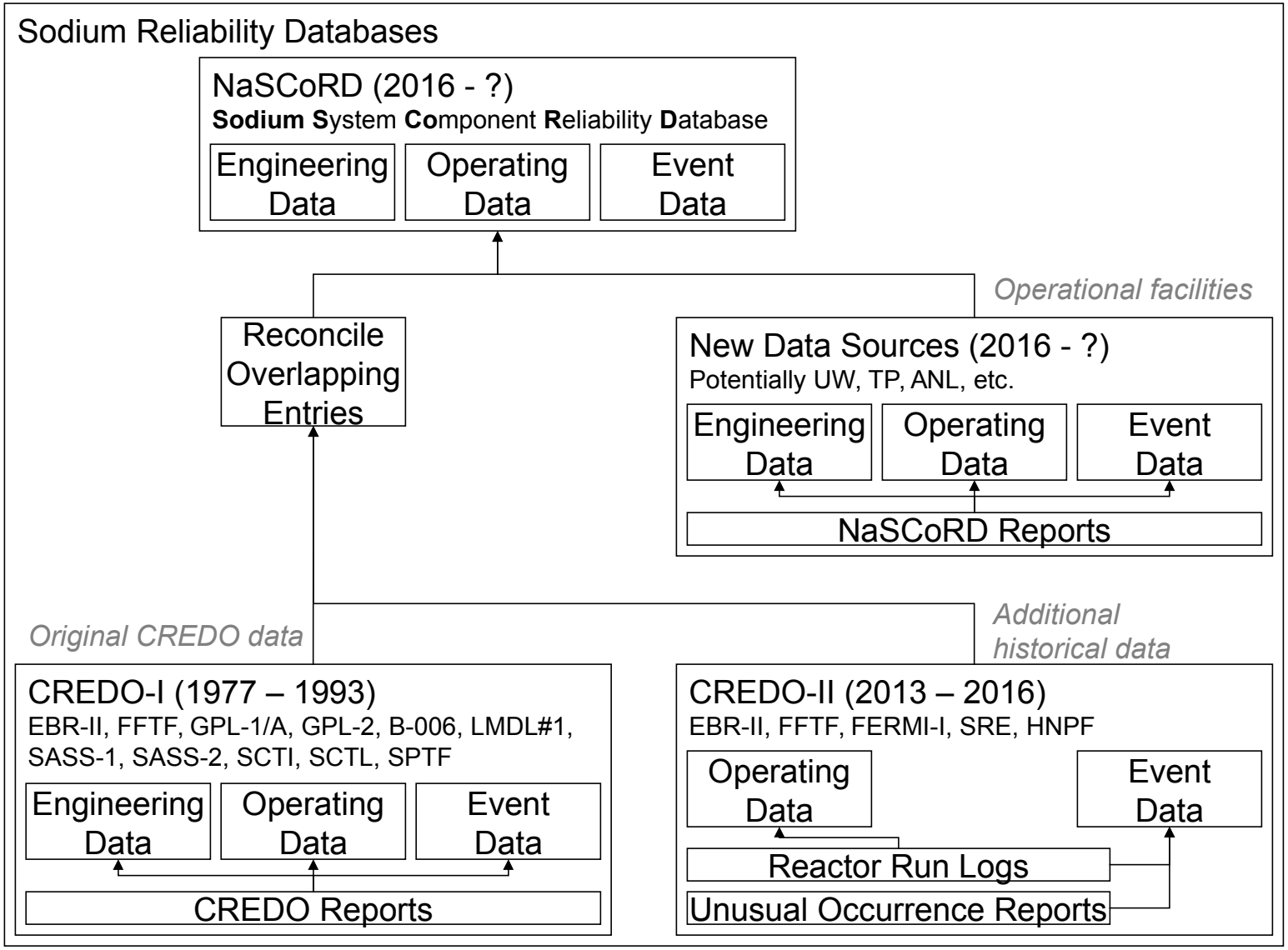


Figure 3: NaSCoRD Data Sources

2 Statistical Analysis

This section summarizes the quantitative contents and applications of the CREDO-I database. The CREDO-I database is undergoing a Quality Assurance (QA) process that will allow the reliability calculations envisioned in this section to be performed with confidence. For the QA steps taken thus far, see Section 3. This section will discuss the following topics:

- Section 2.1 provides a brief overview of the operational, engineering, and event information stored within the CREDO-I Database.
- Section 2.2 describes the path forward for future reliability calculations.

2.1 Summary of CREDO-I Contents

This section presents a high-level summary of the content provided in the CREDO-I database which can be accessed from the SNL SRD website (see Section 5). For more information about the available fields for the CREDO-I database, see Section 5.2.1. This database is divided between operational, engineering, and events data. The following subsections are intended to provide the reader an initial summary of reactor, component, and operating mode information. The database contains many more fields than are presented here. This section is meant to help the reader determine if the type of non-PRA information accessible via the SRD website is valuable enough to request access. The following information is summarized in this section:

- Section 2.1.1 presents the number of hours spent in a given operating mode for FFTF, EBR-II, and various test loops.
- Section 2.1.2 presents the distribution of components logged into the engineering database for reactors and test loops.
- Section 2.1.3 presents the lost hours and number of failures associated with operational phases and component categories across FFTF, EBR-II, and various test loops.

2.1.1 Operational Summary

This section describes the key outputs available within the CREDO-I operational data. The operational data summarize the amount of time that a facility spent in various operating modes. Unplanned outages and special notes regarding the operating period, such as performing an abnormal amount of preventative maintenance, are available in CREDO-I operational data as well. EBR-II operated from 1964 until 1994 and FFTF operated from 1980 until 1992, but the CREDO-I database only contains reactor information up to 1991. The test loops GPL-2, Sodium Components Test Installation (SCTI), Small Component Test Loop (SCTL), and Sodium Chemistry Technology

Facility (SCTF) all contain shutdown information into 1992 but no time in *Isothermal Operations*, the CREDO term for normal test loop operations. EBR-II started increasing its *Power Operations* time from 1971 through 1976 and operated between 5,500 and 7,500 hours per year throughout most of the 1980s. FFTF spent its first four years with significant *Shutdown* periods but leveled off with *Power Operations* hours similar to those of EBR-II throughout most of the 1980s. EBR-II's total reported hours per year were near 8,760 hours (365 days or one year). FFTF's reported hours per year vary dramatically and toward 1990 and 1991 the hours drop significantly. Future efforts will endeavor to reconcile the recorded information with operational documents to ensure that operational mode hours sum up to the number of hours in a given reporting period. The test loops typically reported significant *Shutdown* time in each year with large variations in operating capacity from year to year. The reported annual total number of operational hours for these five test loops add to greater than 43,800 hours, or five times 365 days times 24 hours, on multiple occasions and will need to be investigated in the future.

2.1.2 Engineering Summary

The engineering data provide a detailed summary of a given component within a component class. For example, there may be many types of valves within the component class VALVES, or there may be many of the same type of valve located within the facility. Each piece of equipment is assigned its own component record within the engineering data table. Figures 4 and 5 summarize the number of components within a component class and between component classes for reactors and test loops, respectively. As expected, the total number of components and classes of components across EBR-II and FFTF are much larger than across the test loops. The reactor facilities engineering data are dominated by VALVES, NON-NUCLEAR SENSORS, and PIPE-FITTINGS. The test loops engineering data are dominated by VALVES, PIPING FITTINGS, NON-NUCLEAR SENSORS, and SIGNAL TRANSMITTERS.

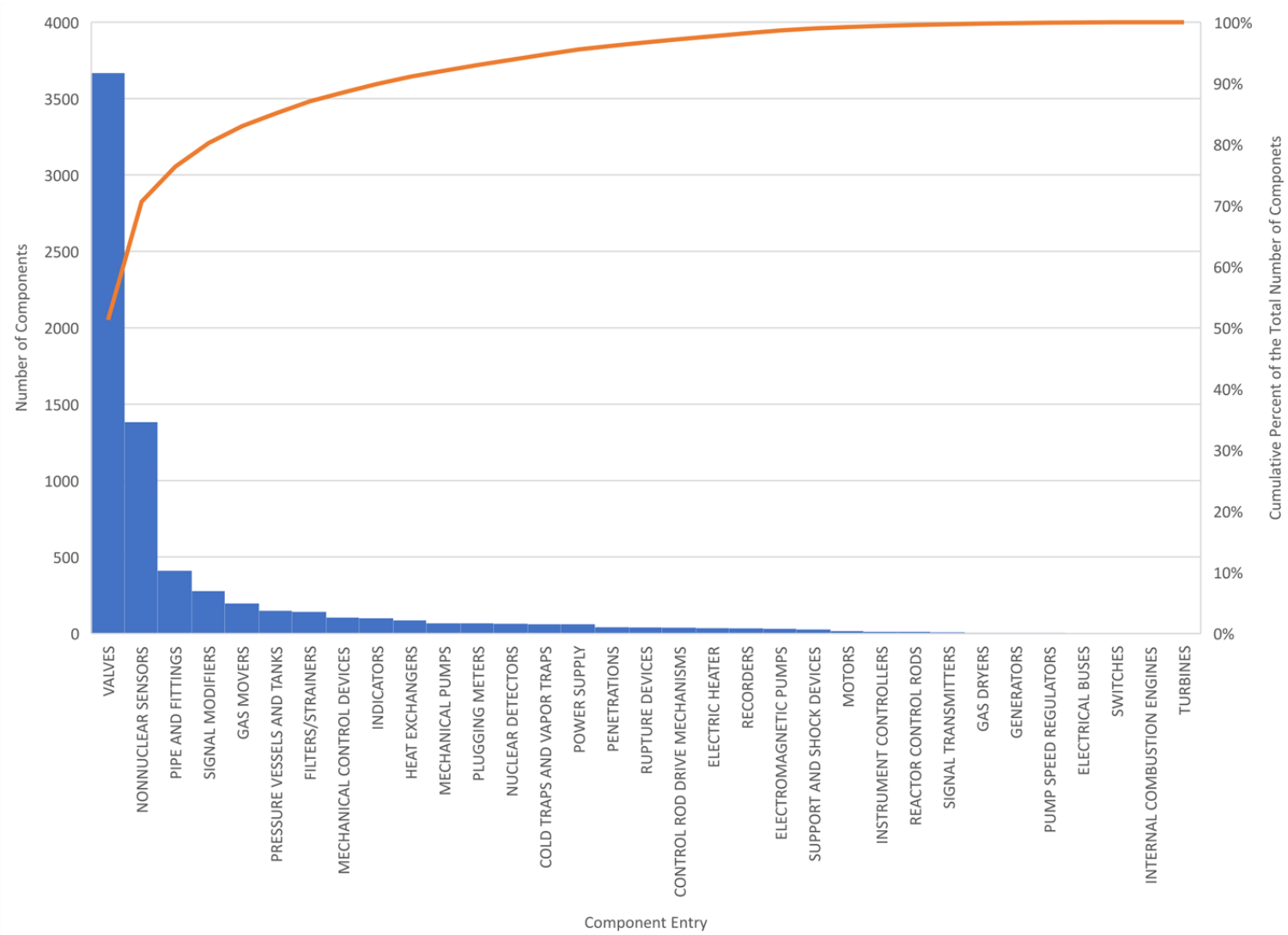


Figure 4: The number of component records within a component class across EBR-II and FFTF.
All component classes have at least one component.

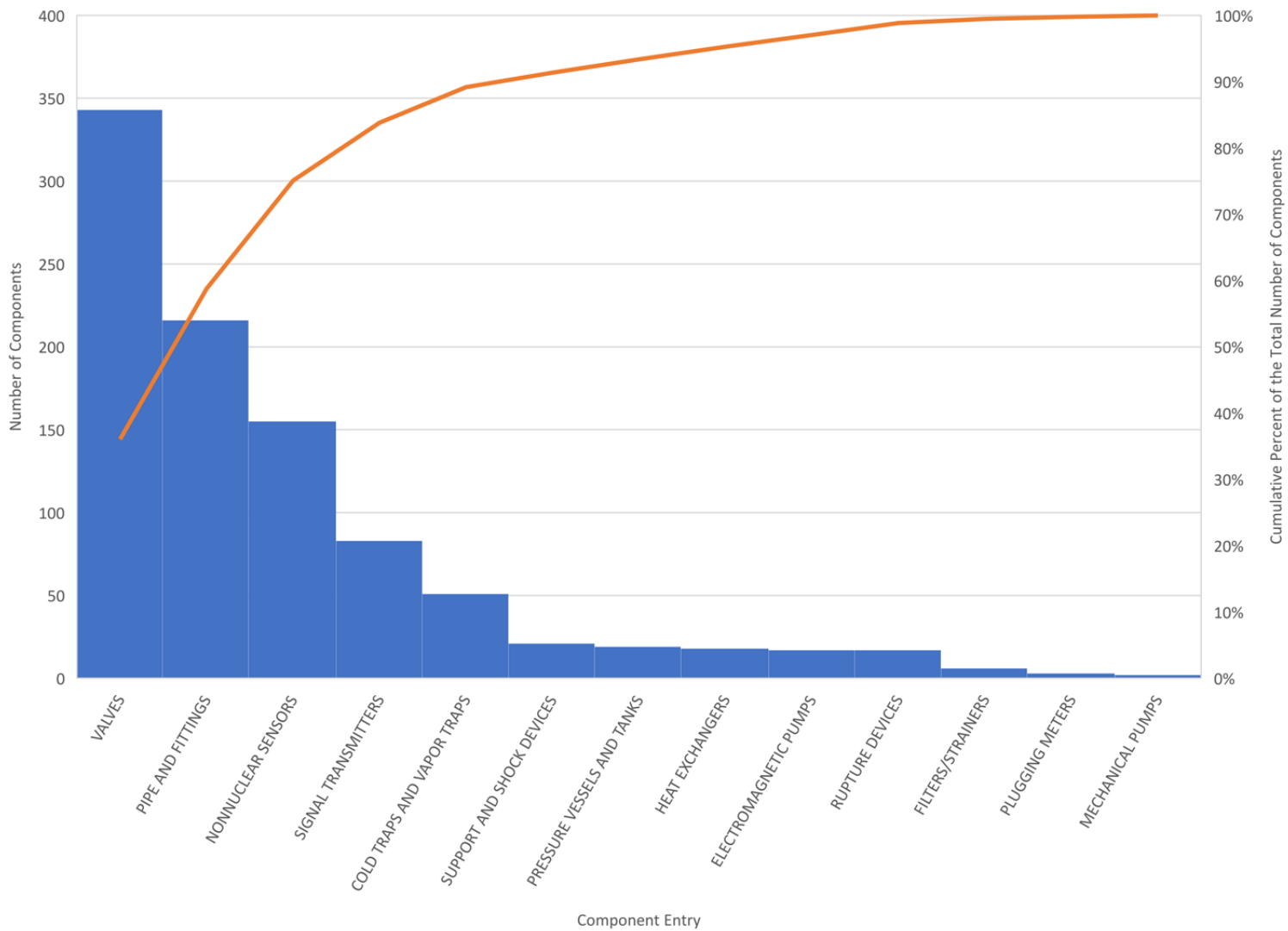


Figure 5: The number of component records within a component class across GPL-1, GPL-2, SCTI, SCTL, and SPTF.

2.1.3 Event Summary

The event data provide information regarding various component failure events. This section will describe how the quantitative event data, namely the number of failures and the schedule impact of these failures to the facilities, can be used to both extract insights on facility performance and uncover potential deficiencies in the underlying dataset.

The event data record the time to system restoration for the component failure events in addition to system/sub-system/component mapping of the failed component and detailed narratives of the failure event, cause, and corrective action. System restoration time is a key driver of the capacity factor, or the fraction of time that the system remains online. A year-by-year summary of failure events at the CREDO-I facilities is given in Figure 6.

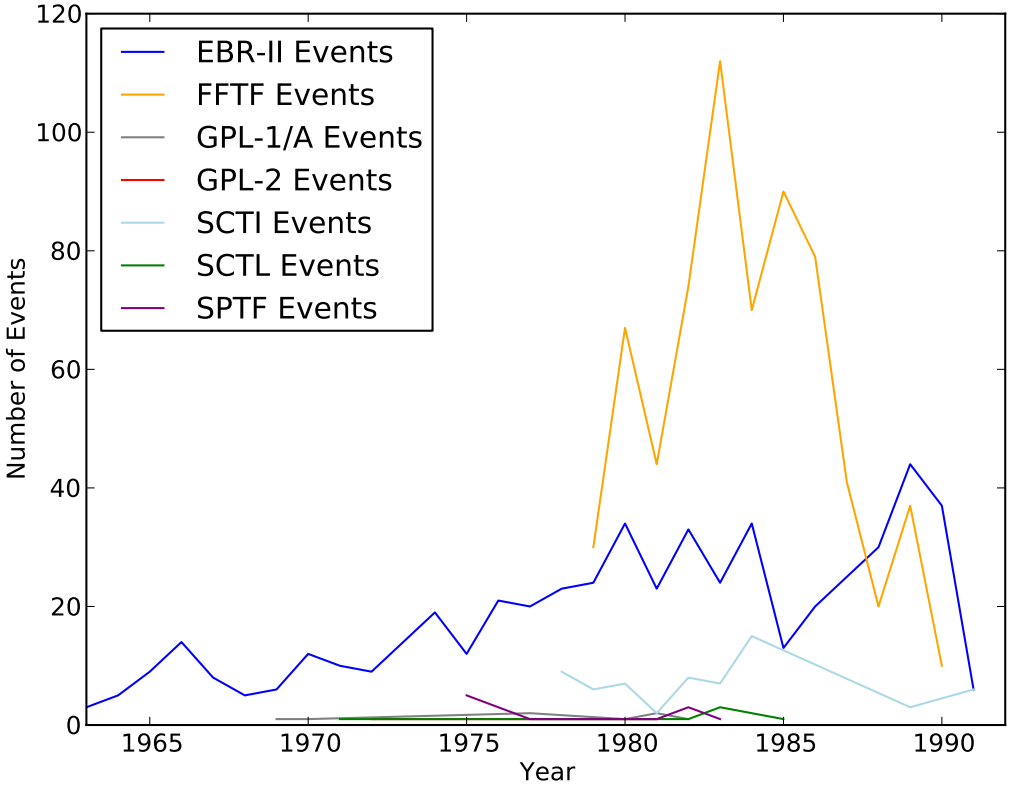


Figure 6: Failure Events at CREDO-I Facilities by Year.

Figures 7 and 8 show the number of failures and the cumulative restoration time for those failures. Both EBR-II and FFTF experienced a plurality of their failures during *Power Operations*. There were differences, however, in the division of failures in other operating modes. EBR-II experienced more failures in *Hot Shutdown* whereas FFTF experienced more failures in *Cold Shutdown* and *Refueling*. Among the test loops, the operational phase corresponding to failures varied dramatically,

with Sodium Pump Test Facility (SPTF) experiencing a relatively high fraction of *Start-Up* failures and SCTI experiencing a relatively high fraction of *Cold Shutdown* and *Refueling* failures.

The resolution time for maintenance events can vary dramatically between types of operational cycles. For example, a facility may desire to delay repairing a complex component until an outage period or the repair time of a component may be accelerated if it forced the reactor to SCRAM. As a result, it can be useful to divide the failure data between operational modes and examine how these modes impact the amount of time spent repairing these components. The relative fraction of restoration hours compared to number of failures for EBR-II increases from negligible in Figure 7 to twelve percent for *Other* operational phases and decreases for *Hot Standby* from thirty to twelve percent in Figure 7, otherwise the relative fractions remain similar. For FFTF, the fraction of restoration time contributed by cold shutdown increases to thirty-three percent from twenty-four percent when only examining the number of failures, possibly indicating reduced schedule pressure for maintenance during outages or more complex maintenance activities being performed during the outage. A preliminary examination of the data suggests that more complex maintenance activities are the driver for increased relative time to repair, but more study is needed to make a definitive statement. For the SCTI loop, the importance of *Thermal/Hydraulic Transient*, *Start-Up*, and *System Drained* failures drop from nearly twenty-four percent of the total number of failures to negligible when examining the time it takes to repair the system, possibly indicating that failures experienced in these modes were easily and quickly addressed or that maintenance record-keeping during these stages were incomplete. A preliminary examination of the data suggests that many events for these modes at the test loops did not report time to recovery. Reliance on these time-to-repair values would require verification via supplemental maintenance information.

By comparing the component data in Figures 4 and 5 with Figures 10 and 11, the reader can infer a first order approximation of whether a component exhibits an outsize impact on the total maintenance activity of a system. From Figure 9, most of the failure data is recorded at EBR-II and FFTF, which is to be expected due to their relative size, complexity, and operational history. The test loops combine to make up approximately seven percent of the total failure database. Figure 10 pools component failure data from EBR-II and FFTF because there are only two reactors within CREDO-I. Insights should be taken with caution because EBR-II was a relatively small pool-type reactor while FFTF was a larger loop-type reactor. Failure events associated with the component class VALVE dominate the event data, followed distantly by GAS MOVERS, SIGNAL MODIFIERS, NON-NUCLEAR SENSORS, and MECHANICAL PUMPS. It is expected that the SIGNAL MODIFIERS and NON-NUCLEAR SENSORS as well as their failure modes will bear limited resemblance to devices used in recent designs. Figure 11 pools component failure data from the various test loops. The component class VALVES still dominates component failures for loops but MECHANICAL PUMPS and ELECTROMAGNETIC PUMPS make up a large fraction of the total failure distribution. As has been shown, the system performance cannot be determined by looking at any one data set in isolation. Only by taking an integral view of the CREDO data can an analyst understand the strengths and weaknesses of the system.

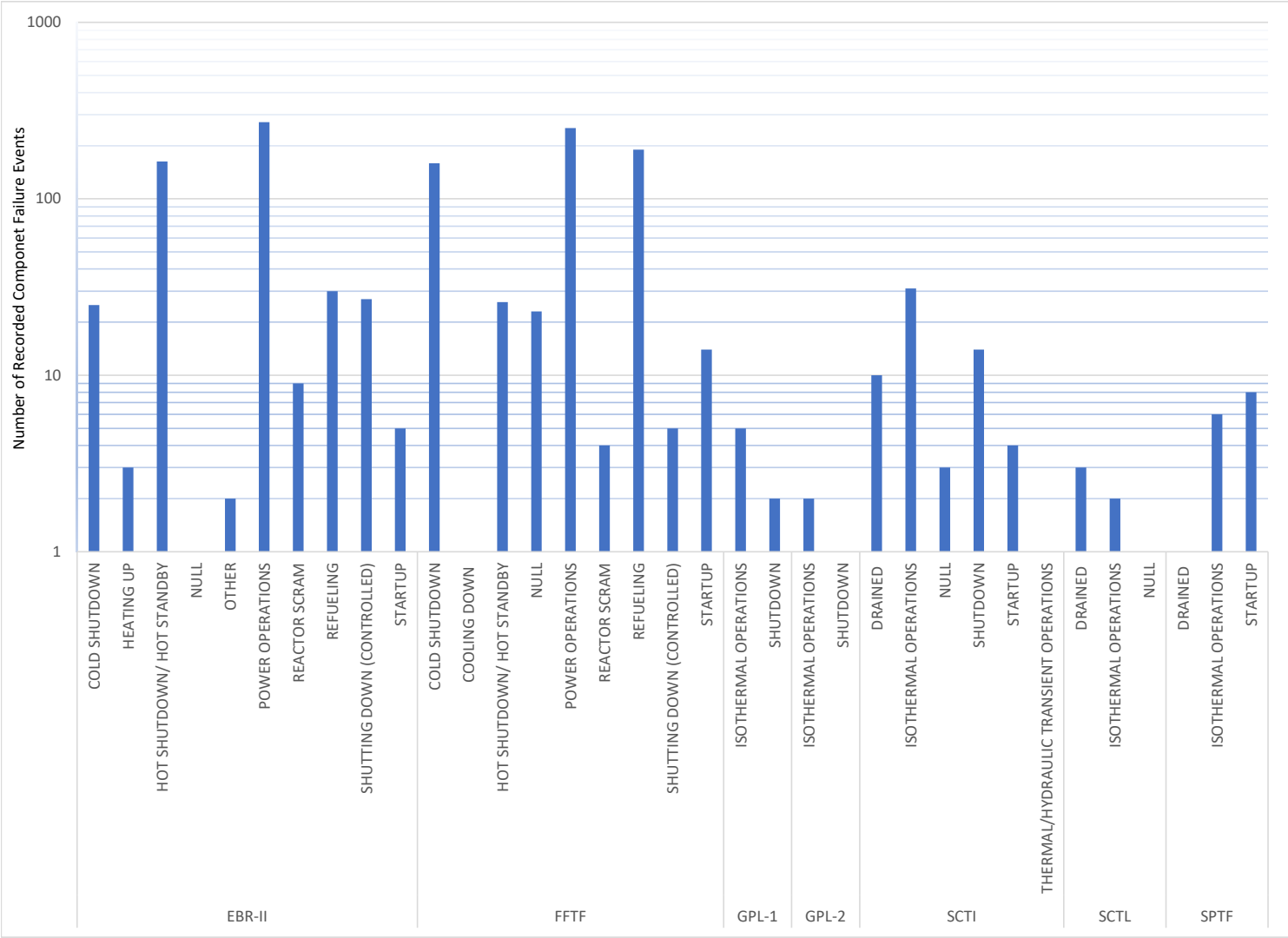


Figure 7: The number of failure events recorded across various facilities and operational phases.

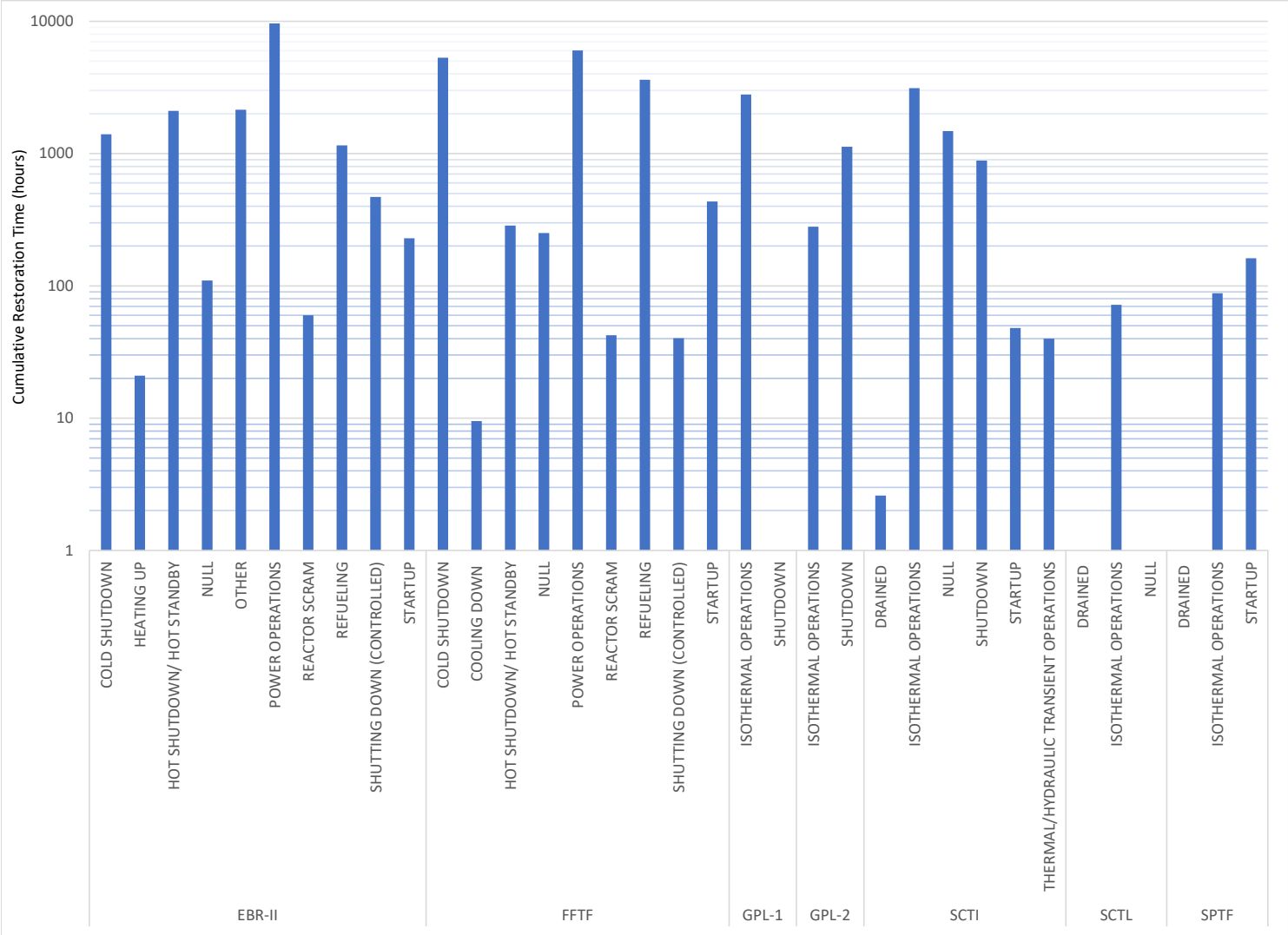


Figure 8: The cumulative time lost to repair from failure events recorded across various facilities and operational phases.

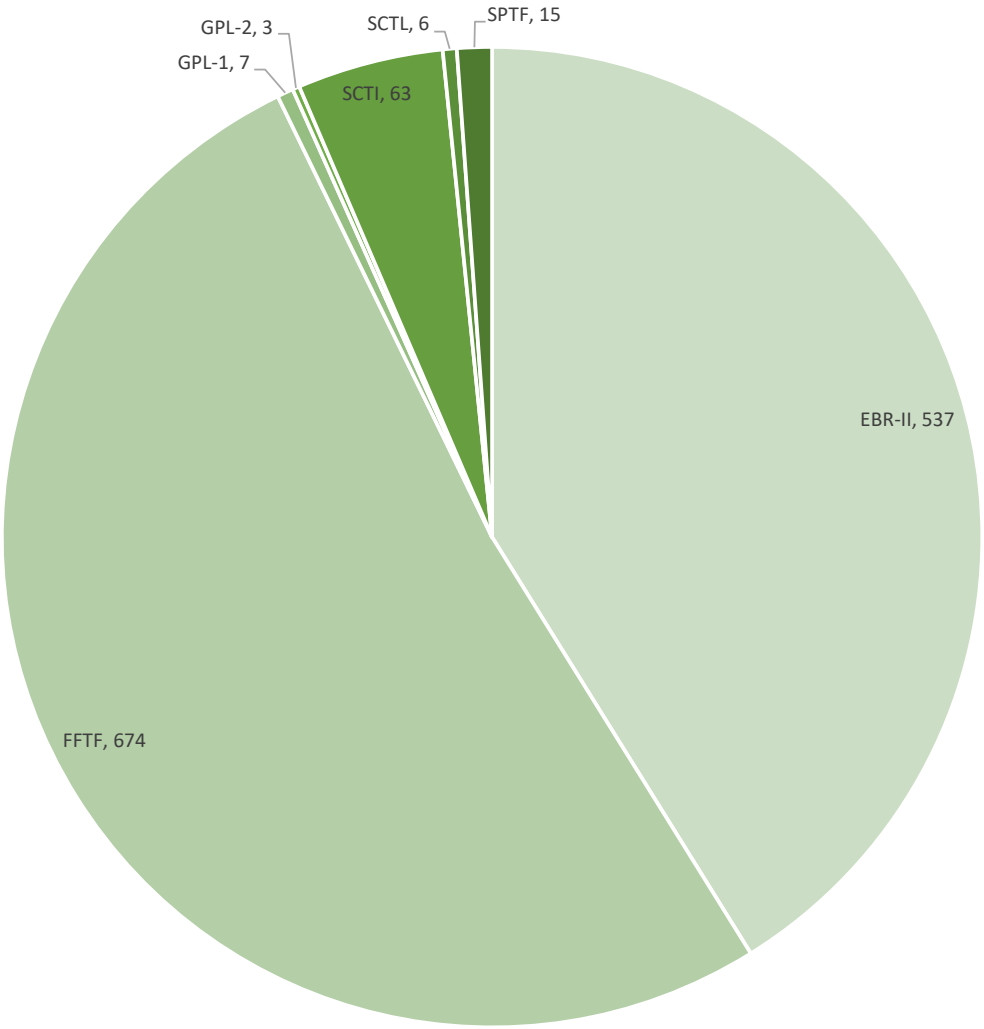


Figure 9: The number of events recorded in CREDO-I for each facility.
Facilities listed in alphabetical order.

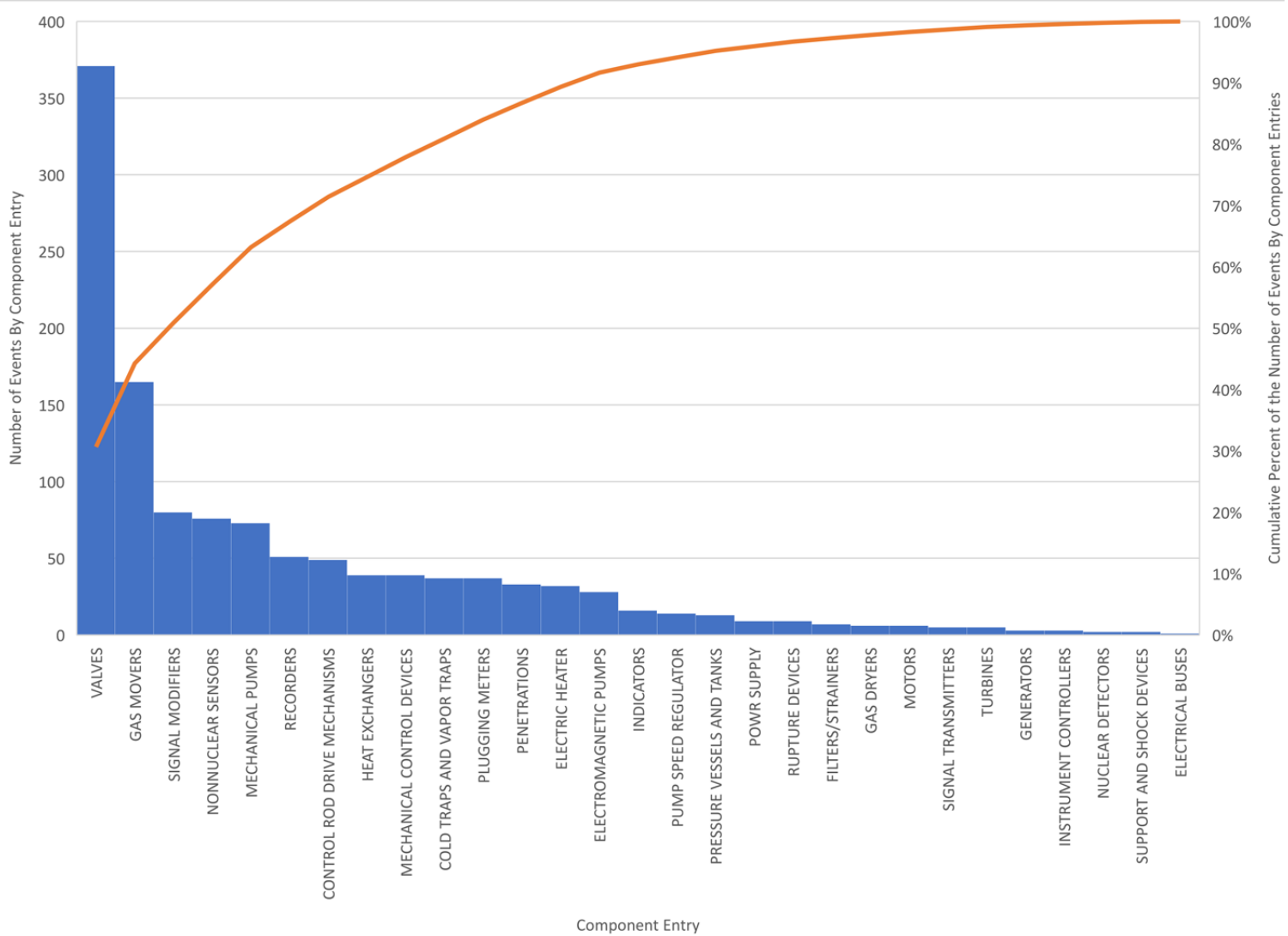


Figure 10: The number of failure events divided by component class across EBR-II and FFTF.

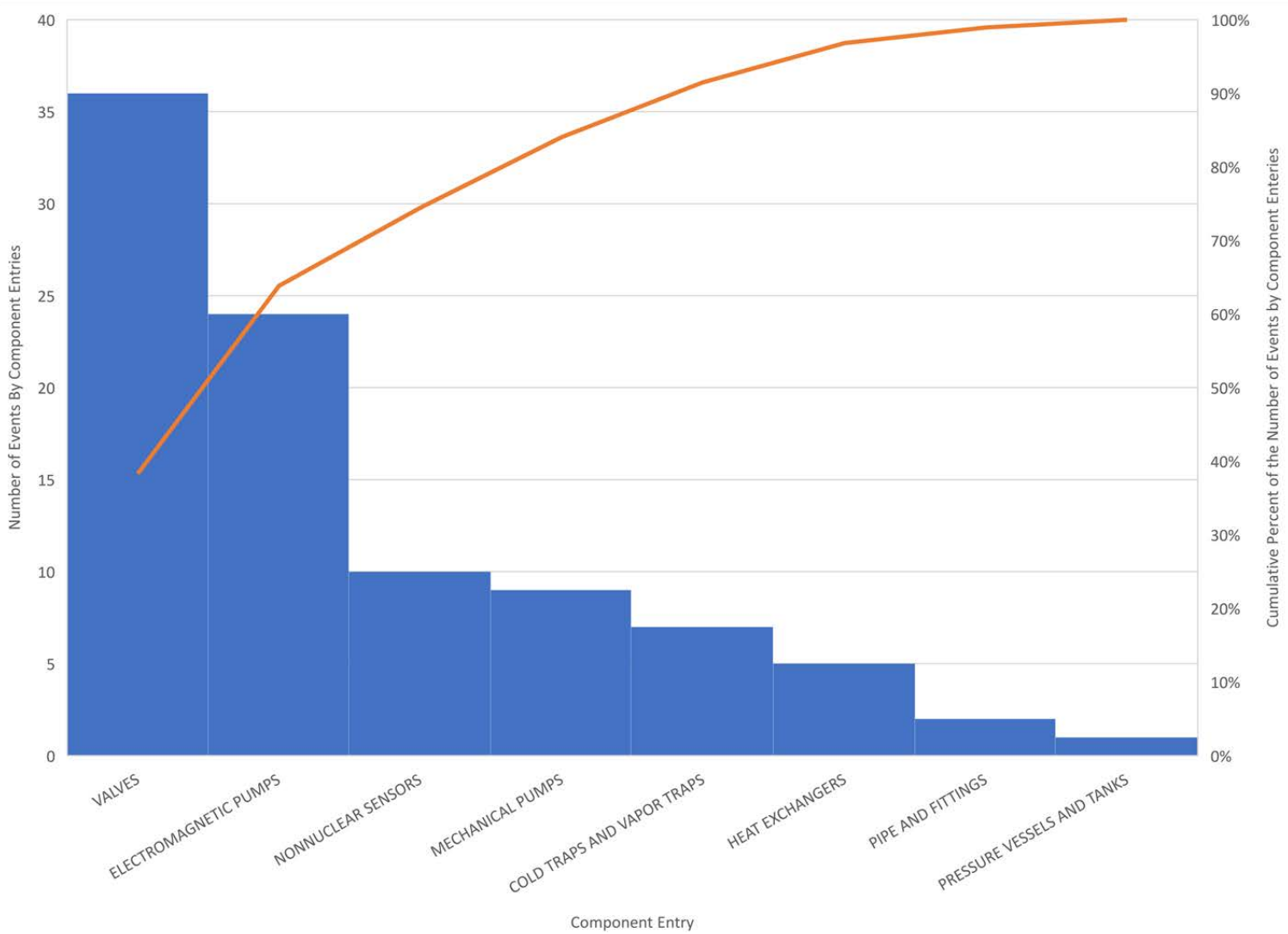


Figure 11: The number of failure events divided by component class across GPL-1, GPL-2, SCTI, SCTL, and SPTF.

2.2 Future Reliability Analysis

One of the primary purposes of CREDO was to perform reliability estimates of components to inform PRAs. The first stage of establishing reliability calculations for PRA based on the CREDO-I data is to implement basic calculations based on a Bayesian update of a non-informative prior [21, p. 6]. Depending on a component's type, it can experience time-related failures and/or demand-related failures. Equations 1 and 2 are initially used to develop failure estimates for time-related and demand-related failures, respectively.

$$f_{failure}|n,T = \frac{2n+1}{2T} \tag{1}$$

$$p_{failure}|n,D = \frac{2n+1}{2D+2} \tag{2}$$

In these equations, T is the total operational hours for all components in a given class, D is the total demands for all components in a given class, and n is the total number of failures experienced in T hours or D demands, respectively.

After this initial assessment, more informative priors are investigated. This allows for the inclusion of errors for the above point estimates. Various prior distributions are introduced for different failure modes [22, p. C-9].

There are remaining complexities that can be investigated after the above baseline estimation of the distribution of failure probabilities and frequencies [23, p. 11-43]. The first thing to consider would be various maintenance schedules and procedures for the given component groups. If one reactor unit has a more rigorous inspection and maintenance schedule than another, then its components should be expected to have fewer failures. By accounting for inspection and maintenance, along with the censoring effects that it has on failure rates, a better estimate may be obtained for the failure rates. This general statistic would be of significant interest to plant operators. While this is a far more complex task, it would allow for further refinement of reliability data for the component.

To date, the focus of the SRD effort has been to interpret and assess the quality of the available SRD data while future efforts will ensure that the utilization of this data is appropriate for each intended application. Previous assessments have criticized [21, p. 5] the direct, unadjusted use of the CREDO data in power reactor PRAs because the scale and operating modes of power reactors are significantly different than those of test reactors. The ongoing implementation of reliability analysis attempts to address this criticism.

3 CREDO Data Quality Assurance

The user needs to have confidence that the underlying data is trustworthy in order for safety insights to be gained from the CREDO-I data-set. The partial copy of the original CREDO data that was received by SNL was considered to be of unknown provenance. It had traveled internationally and had likely undergone several data storage format changes since leaving DOE custody in the early 1990s and returning as a Microsoft Excel 2007+ spreadsheet in 2016 [4].

Analyses were performed to check the integrity of the recovered data against errors which may have been introduced at the time of initial data entry or during subsequent conversions. While the database was converted to SQL, the analyses described in this section were generally performed with an offline copy of the data (see Section 3.1). Corrections were documented and uploaded to the authoritative SQL database.

A number of inconsistencies and errors were discovered and corrected (see Table 3). To date, QA has been performed by checking consistency between CREDO-I and CREDO-II and internally within CREDO-I. In future efforts, studies previously performed using the CREDO data (e.g., Reference [15]) may be replicated to further check data integrity. The following sections summarize the results of the QA process to date:

- Section 3.1 outlines the evolution of software QA requirements for NaSCoRD.
- Section 3.2 describes efforts to ensure that the operational data is internally consistent and well-defined.
- Section 3.3 identifies missing engineering data that was not included in the CREDO-I database.
- Section 3.4 describes efforts to enforce consistency in restoration time records within the event data.

3.1 NaSCoRD Quality Assurance

NaSCoRD will be operated in Microsoft SQL under SNL's corporate database administration environment. All NaSCoRD reports (see Section 1.1) will be developed and administered using these tools. However, while the initial data assessments are being conducted, python scripts are currently being utilized to interrogate the data. All record (see Section 1.1) modifications resulting from a QA examination of the CREDO database are recorded in the corresponding *Notes* or *Remarks* record and the NaSCoRD developer's name is recorded in the signature field. Recent versions of Microsoft SQL have integrated services for the R statistical programming language which will allow the NaSCoRD development team to take advantage of Microsoft's Software QA [24].

Table 3: Suspected Erroneous Data in CREDO-I

Facility	Entry Type	Suspected Error	Corrective Action	Reference
EBR-II	Operational	Trailing 0 in output record	Removed 0	Section 3.2.4
EBR-II	Operational	Output exceeds design power by 6%	No action taken	Section 3.2.5
FFTF	Operational	Output exceeds design power by 7%	No action taken	Section 3.2.5
FFTF	Operational	Output exceeds design power by 7%	No action taken	Section 3.2.5
SPTF	Operational	Overlapping entries	Entries adjusted	Section 3.2.6
Multiple	Event	Restoration hours given as "-1"	Entries adjusted to "0"	Section 3.4

3.2 Operating Data Quality

The data QA effort for operating records has focused on the following:

- Section 3.2.1 describes the process of obtaining an offline copy of the data for further analysis.
- Sections 3.2.2 and 3.2.3 document efforts to independently determine the meaning of output measures and operating modes in the CREDO-I data.
- Sections 3.2.4 and 3.2.5 examine the output data from CREDO-I for outliers.
- Section 3.2.6 identifies overlapping reporting periods experienced in CREDO-I.
- Section 3.2.7 describes unexpected logic in the relationship between operating factors and duty factors.

3.2.1 Offline Data Processing

A number of functions were written in the python programming language to interrogate the database, rather than performing operations using the SQL of the host database. This gives somewhat greater flexibility in using conditional and mathematical programming functions, as well as the ability to directly plot results. This was accomplished using an offline copy of the database for convenience.

The insights gained from offline analysis were incorporated into the CREDO-I database where appropriate. The database was exported using standard tools as described in Section 3.2.1.1, and then read into offline processing functions using the process shown in Section 3.2.1.2.

3.2.1.1 Database Export Format

Interrogation of the CREDO-I and CREDO-II databases offline first required the data to be saved in a common format. The database server uses Microsoft SQL Server 2012, and information was extracted to the Microsoft Excel 97-2003 format using built-in tools from the Microsoft SQL Server Management Studio. Upon exporting the data from the SQL database, only definitional relations were added to the JAEA-delivered data, which contained no relationships. Though currently feasible, offline data analysis may become impractical as more relationships are identified and added to the CREDO-I database. By this time the data analysis process will have completely migrated to R within Microsoft-SQL (see Section 3.1). The original CREDO-I data and accompanying information were saved as the file *CREDO-I.xls* and CREDO-II was saved as the file *CREDO-II.xls*. The tables of information in each file are listed in Table 4 and Table 5, respectively.

Table 4: CREDO-I.xls Table Contents

Table Name	Description
EngineeringData	System configuration information
EventData	Reliability and failure event information
OperatingData	Operating history information

Table 5: CREDO-II.xls Table Contents

Table Name	Description
action	Type of action taken following an event
daily_history	Operating history information
documents	Source documents used in gathering data
event	Reliability and failure event information
event_system_diagram	Specific sub-system affected for each event
run_history	Operating history information
system_diagram	Hierarchical relationships of systems, sub-systems, and components

3.2.1.2 Reading Exported Database Files

The data files created in Section 3.2.1.1 are parsed by a function named `sfr_pickle`, which translates the information into a python-friendly form. The information is formatted into a python dictionary, which acts as a container for other data types. Each entry of this dictionary is a table

name (see Tables 4 and 5), which contains a list of the rows of the table. When the offline analysis tools are run, a data file name such as *CREDO-I.xls* or *CREDO-II.xls* is specified, and `sfr_pickle` will be run to convert the data if it has not already been done. The user would only manually call `sfr_pickle` if a converted data file with no associated data analysis is desired.

3.2.2 Parsing CREDO Output

As received, CREDO-I included numerical operating data under terms such as *Design_Output*, *Authorized_Output_This_Report_Period*, and *Report_Period_Total_Output* with no explanation of their meaning or units. A document [25, p. 20-21] recovered later confirmed that the CREDO-I output for EBR-II is indeed the electrical production. Before this document was secured, the NaSCoRD development team attempted to use CREDO-II data to back-fit units onto these CREDO-I records. This process could not be performed for FFTF, as detailed operating information for FFTF could not be found for inclusion in CREDO-II. In the CREDO-I operating data reporting form, the only explanation that is provided is [8]:

> Output units depend on type of facility and are specified by mutual agreement of CREDO and site staffs.

With no suggestions regarding the appropriate definitions or units from the CREDO input forms, attention turned to the previous data collected for CREDO-II. A large amount of information was available regarding EBR-II operational states in CREDO-II including the number of hours in each state and the thermal and electrical power production, in some cases on a daily level. There is no daily operational information available in CREDO-I. The CREDO-II was used to identify the meaning of the outputs in the CREDO-I data. The summed thermal and electrical production from CREDO-II for each year of EBR-II operation were each plotted alongside the summed CREDO-I *Report_Period_Total_Output* values for the same years as shown in Figure 12. Some deviations between the CREDO-I Output and CREDO-II Electric data will be investigated in Section 3.2.4.

Visual examination of Figure 12 yielded numerous years when the CREDO-II electrical output and the CREDO-I output were nearly identical. This was not the case for all years due to apparent gaps in data reporting for both databases. The tendency toward overlapping data points for CREDO-I output and CREDO-II electrical output suggested that they measure the same physical value in the same units. No changes were made to the data as a result of this examination but it did serve to reinforce the definition of output in [25].

3.2.3 Parsing CREDO Operating Modes

Similarly to the lack of output unit labels (see Section 3.2.2), the CREDO-I database contained information about three numbered operating modes for each facility but with no description of what each operating mode signified. A document recovered later [25, p. 20,57] revealed the meaning of all numerical operating modes:

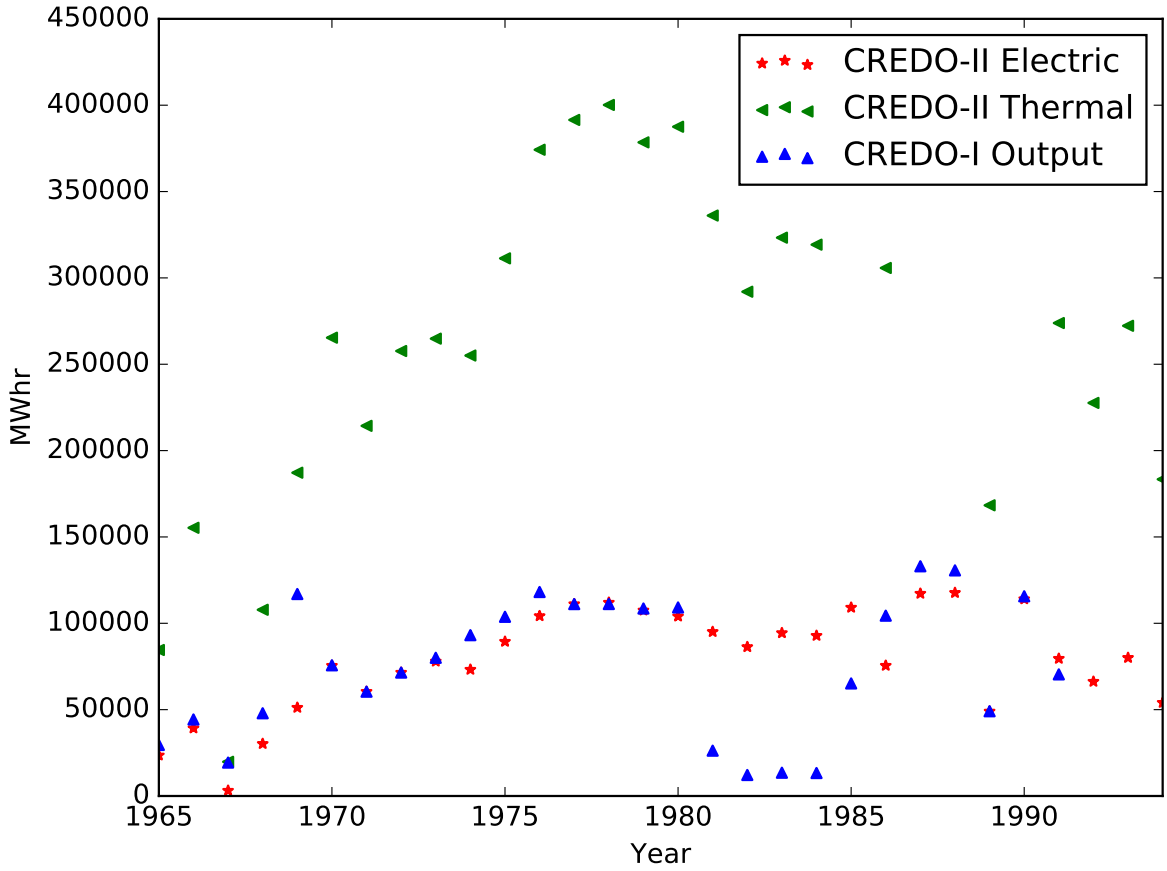


Figure 12: CREDO-I Output Unit Determination, EBR-II.

- Operating Mode 1: Operating
- Operating Mode 2: Transition (startup, shutdown, or hot standby)
- Operating Mode 3: Shutdown (cold)

Before this document was recovered, the NaSCoRD development team realized that there were entries in CREDO-II for reactor critical time that could potentially identify one of the operating modes for EBR-II. The script `determine_credo1_operating_mode` was written to use the daily values of reactor critical time in CREDO-II to attempt to determine which CREDO-I operating mode signified power operations for EBR-II. There were 7,726 daily records available for EBR-II, covering approximately seventy percent of the days in its thirty year operational period. The daily reactor critical hours were summed for each year, as were the times in each of the three CREDO-I operating modes, and the results are plotted in Figure 13.

Visual inspection of Figure 13 shows nearly identical values between the CREDO-II critical time and the CREDO-I operating mode 1 time for multiple years. In most years, the critical time was nearer to operating mode 1 time than to the times spent in other operating modes. The frequent overlap suggested that CREDO-I operating mode 1 represents reactor power operations. As in

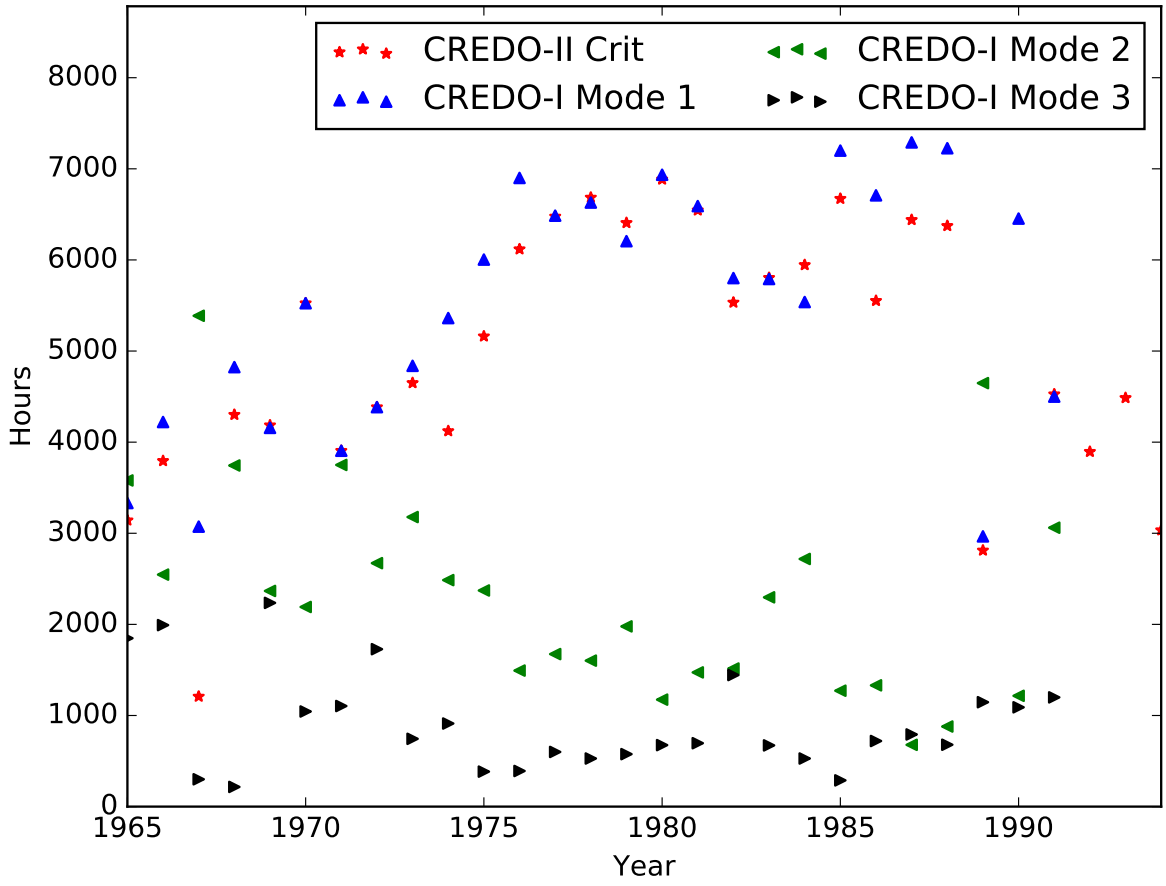


Figure 13: CREDO Operating Mode Determination, EBR-II

Figure 12, this comparison is subject to missing data in both databases. There was not sufficient information in CREDO-II to identify the other two operating modes for EBR-II as the only other time record in CREDO-II is the generator operating time. This process was not repeated for FFTF as detailed operating information was not available for inclusion in CREDO-II. No changes were made to the data as a result of this examination but it did serve to reinforce the definitions of operating modes from [25].

3.2.4 The Case of the Overproductive Reactor

While ensuring that operational data from CREDO-I (see Section 4.4) used a standardized set of units, a potential outlier was identified. Each operating data entry for EBR-II in CREDO-I accounts for approximately three months, and for most entries the authorized power level was at or near the design power of 20 MWe. Because it was an experimental reactor, EBR-II commonly had periods with a low capacity factor. For example, to allow for old experiments to be removed and new ones to be set up. The number of hours in power operations for each period are plotted against the recorded output in Figure 14, with the line of 20 MWe in blue. Entries generally should not appear

above the line, as that would suggest that during that time period the reactor averaged output above its design power level, which is unlikely for an experimental reactor.

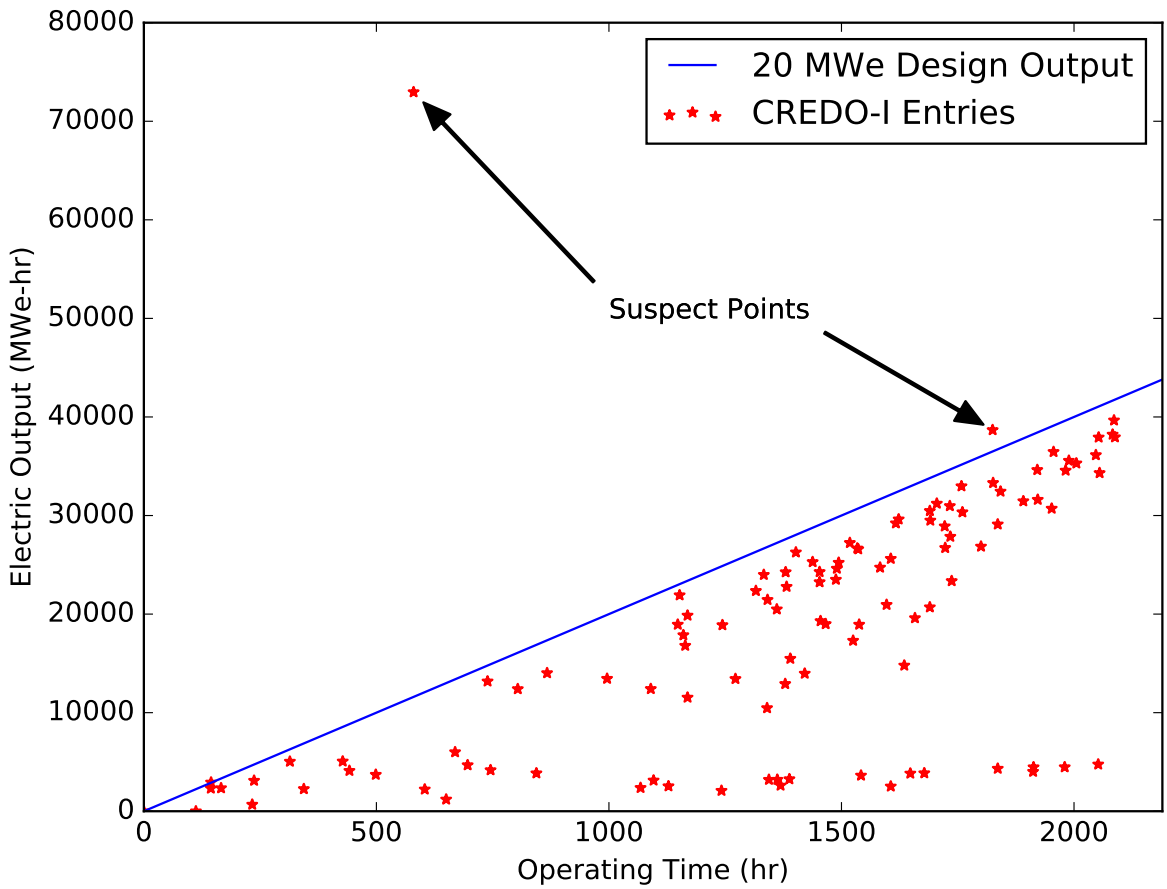


Figure 14: CREDO-I Outlier Detection, EBR-II Operating Data

The value given in CREDO-I for the most suspect point, in the upper left of Figure 14, was *72960* MWe-hr. This was initially suspected to be an order of magnitude error, with an extra *0* inserted unintentionally at the end of the entry. CREDO-II daily history was available for many of the days in the time period covered by the suspect entry in CREDO-I. The daily output and accumulated output throughout that period are plotted in Figure 15.

The daily histories in Figure 15 (in black, measured on the left axis) sum to 7296 MWe-hr (in blue, measured on the right axis), which strongly suggests that a simple order of magnitude error was present in the CREDO-I data in Figure 14. The value was corrected in the database and a note was added to explain the change in the CREDO-I database. This revelation is one example of the value of the CREDO-II database in checking the integrity of the CREDO-I data.

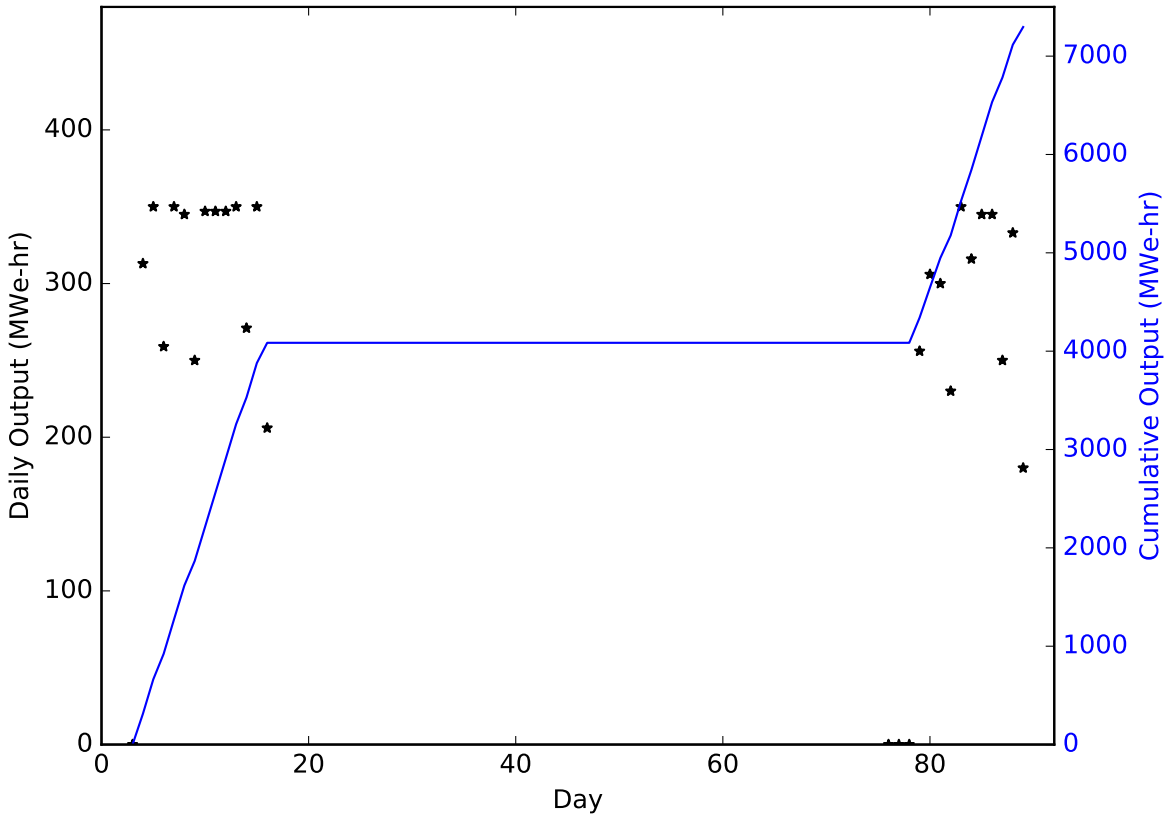


Figure 15: CREDO-I Outlier Detection #1, CREDO-II Sourced EBR-II Operating Data. Coverage is the period represented by the upper left suspect point in Figure 14.

3.2.5 Blurred Lines

The inclusion of a line of 20 MWe revealed a second suspect point, just above the line in Figure 14 at *38680* MWe-hr. This represents an average electrical output of 21.2 MWe for the reporting period. This data point was investigated by similar means, and the daily and cumulative history for the time period from CREDO-II are presented in Figure 16. The daily history in CREDO-II suggests that the cumulative electrical output in this period is 23207 MWe-hr. While this represents a significant discrepancy, there is no obvious explanation (such as an erroneous trailing 0) for the *38680* value. This discrepancy may motivate the preference of one set of operational data over the other, as described in Section 4.5. This particular point was selected for greater scrutiny because it crossed the line of design output. Multiple years may be seen in Figure 12 where there are significant differences between the CREDO-I output and the electrical output from CREDO-II for EBR-II. This phenomenon will be explored for all CREDO-I EBR-II operational entries in the coming year.

Operating hours in each CREDO-I reporting period were also plotted against recorded output for FFTF in Figure 17. In this case the blue line represents the design thermal output of 400 MWt. There are two reporting periods where the output (255,360 MWt-hr and 866,880 MWt-hr) exceed the 400 MWt line by a small amount (429 MWt and 427 MWt, respectively). There are no clear

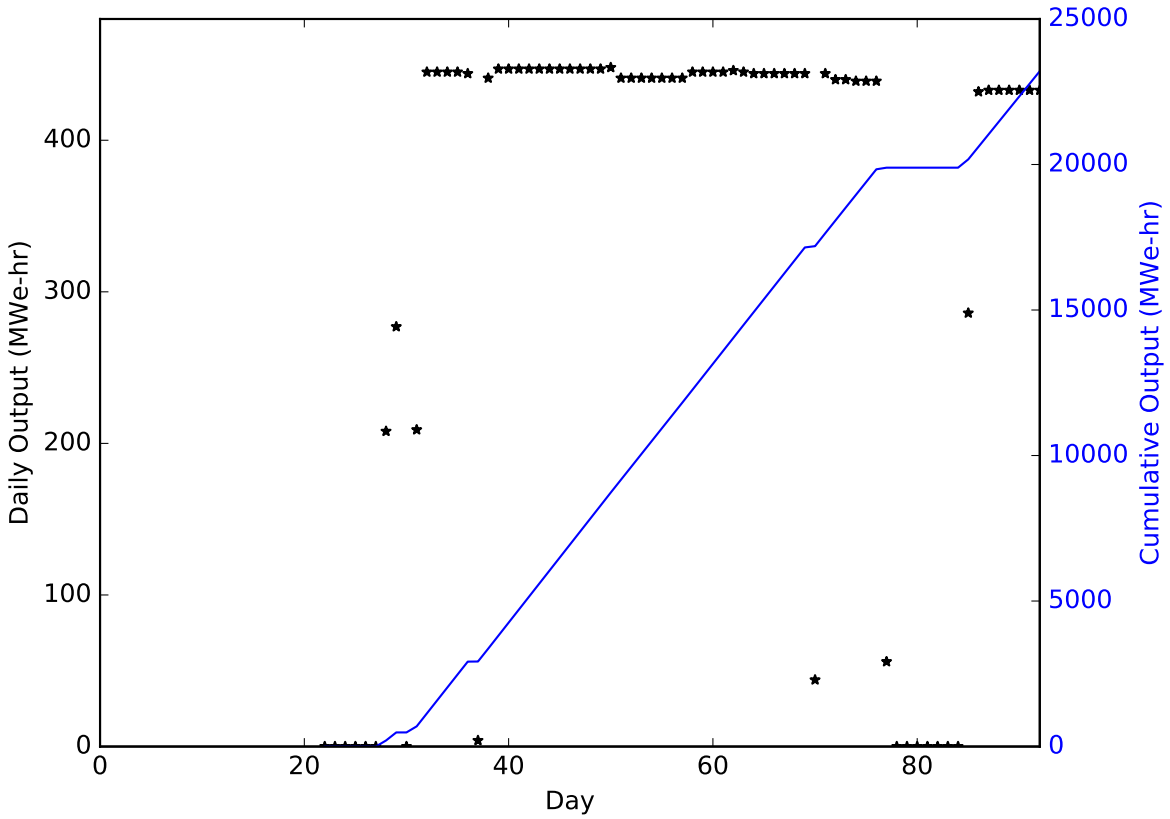


Figure 16: CREDO-I Outlier Detection #2, CREDO-II Sourced EBR-II Operating Data. Coverage is the period represented by the middle right suspect point in Figure 14.

discrepancies in the corresponding CREDO-I entries, and at the time of writing no independent operating data have been gathered for FFTF. One potential explanation is that significant thermal output accumulated in operating modes other than power operations.

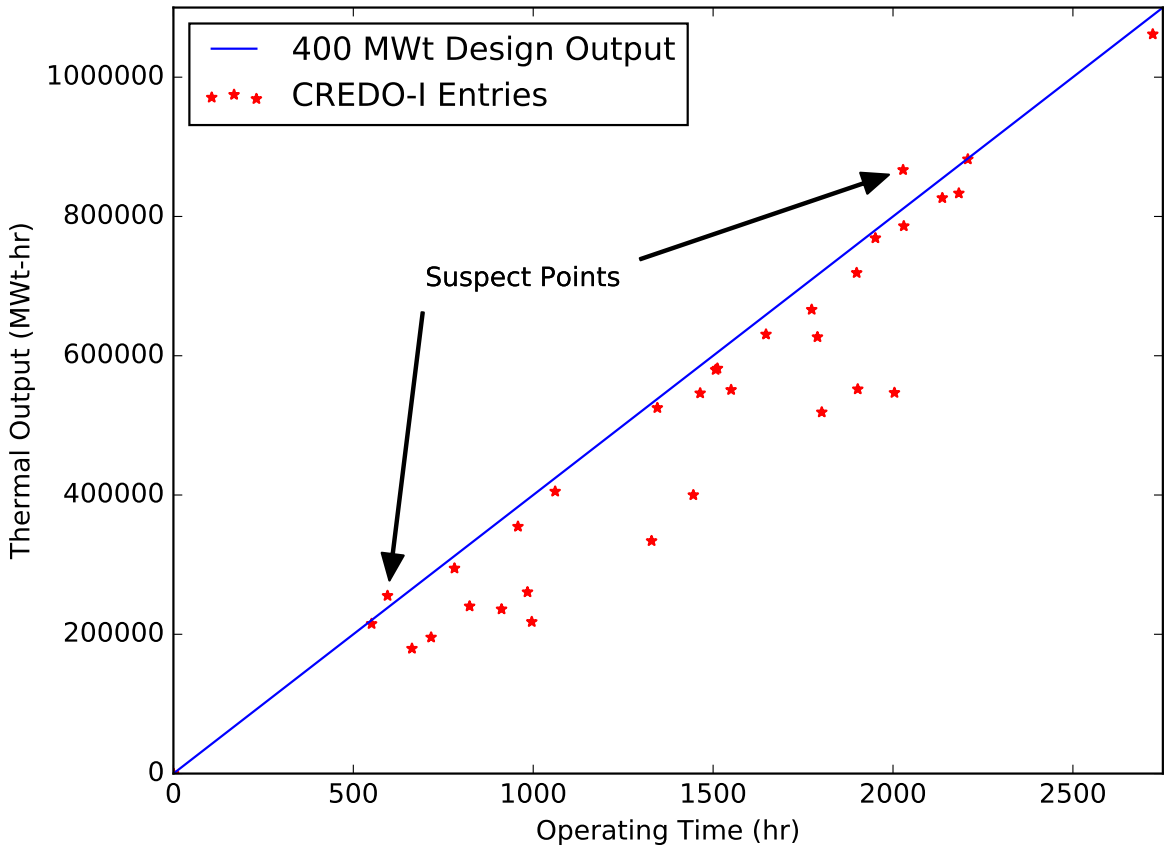


Figure 17: CREDO-I Outlier Detection, FFTF Operating Data

3.2.6 Overlapping Operational Information

There was one instance in the CREDO-I data of an overlap in operational data. When creating reports for CREDO-I events (see Section 5.2.1.3) it was assumed that at most one operational data entry would cover each event. Note that this will not be assumed in NaSCoRD (see Section 4.5). Table 6 shows the overlapping entries for a thirteen month reporting period. Record 1 contains an operational period as well as a period following a scheduled stoppage. Record 2 contains only the period after the stoppage. Because of this unique relationship, the overlapping entries may be separated.

Table 6: CREDO-I Overlapping Operational Information (original)

Parameter	Operational Record 1	Operational Record 2
Start Date	08-31-1981	07-01-1982
End Date	09-30-1982	09-30-1982
Operating Mode 1 Hours	4,176	0
Operating Mode 2 Hours	576	0
Operating Mode 3 Hours	4,728	2,208

Table 7: CREDO-I Overlapping Operational Information (edited)

Parameter	Operational Record 1	Operational Record 2
Start Date	08-31-1981	07-01-1982
End Date	06-30-1982	09-30-1982
Operating Mode 1 Hours	4,176	0
Operating Mode 2 Hours	576	0
Operating Mode 3 Hours	2,520	2,208

Between the start and end dates of Record 1 there are 9,480 hours, or thirteen months, which is equal to the sum of the recorded time in operating modes 1, 2, and 3. Likewise, Record 2 accounts for all of the time in its stated range. Table 7 shows the adjustment that was made to Record 1 to eliminate the overlap. The operating mode 3 represents shutdown (see Section 3.2.3), where the time of Record 2 has been subtracted from that of Record 1. The end date of Record 1 has been adjusted to be the day before the start date of Record 2.

3.2.7 Factor Uncertainty

The CREDO data input guide [25] defines the operating factor for each operating mode (see Table 8) as the percent of the time the component operates when unit is in that operating mode. The duty factor is defined for each operating mode as average number of times per hour the component is cycled when the unit is in that operating mode.

Based on these definitions, it was expected that components with nonzero duty factors for a given component would also have a nonzero operating factor for the given mode. This expectation is not always satisfied in the CREDO-I data. There are 104 components that have a capacity factor of zero for a given operating mode, along with a nonzero duty factor for that mode.

This feature of the data will require further investigation, as there is no clear pattern of which components and/or operation modes are more likely to have this occur. Confirmation of the true relationship will likely be possible if prior CREDO studies are replicated or if further literature is discovered. It is hypothesized that the operating factor only refers to components that operate continuously for the given mode (e.g., pumps) and the duty factor refers to components that only

Table 8: Operating Mode Definitions

Type of Facility	Mode 1	Mode 2	Mode 3
Reactor	Power Operations	Hot Standby	Cold Shutdown
Non-Reactor	Isothermal Operations	Shutting Down, Startup, Thermal-Hydraulic Transient Operations	Drained, Shutdown

Table 9: CREDO-I Events with no Engineering Data

Event Number (generic)	Event Start Date	Restoration Hours	First Component Install Date
1	12-31-1980	1	N/A
2	07-31-1981	N/A	07-31-1981
3	10-06-1982	80	03-25-1983
4	08-06-1986	5	10-23-1986
5	08-25-1978	0	10-13-1978
6	07-18-1975	8	12-23-1975
7	07-18-1975	4	12-23-1975
8	07-18-1975	14	12-23-1975
9	07-18-1975	6	12-23-1975
10	07-01-1975	24	12-23-1975

cycle during that mode (e.g., valves).

3.3 Engineering Data Quality - Missing Engineering Information

Component entries in the CREDO-I database include an installation date. When a particular component requires replacement, its entry also includes a removal date. A number of events in CREDO-I are associated with components for which there is no corresponding engineering data entry at the time of the event, as shown in Table 9. In all but one case (Event 1), an engineering data entry was created with an installation date within months after the event. It is hypothesized that some components were only added to CREDO after an event relating to them occurred. There was no corrective action taken as a result of this discovery but it is noted for posterity.

3.4 Event Data Quality - Inconsistent Restoration Data

The QA process for event data has focused on the treatment of restoration data, which will be vital for conducting capacity factor calculations.

For thirty two distinct components, CREDO-I failure event entries were given with total restoration man hours[1] equal to "-1". In twenty nine such cases, there was a single restoration man hour subcategory, i.e., *Administrative Man*, *Logistics Man*, *Indirect Repair Man*, *Direct Repair Man*, *checkout restart man*, also populated with "-1". In the remainder of cases, another subcategory was populated with a non-negative value, which made the total restoration man hours non-negative.

The "-1" value may be found at some later point to have a specific meaning. Every entry that was adjusted is marked as such in NaSCoRD with a description of the change and when it was made.

[1] Term used in CREDO to refer to labor charges associated with an event.

If an affected data point is used in a reliability calculation, the tools built to use the NaSCoRD data will warn the user of this fact and allow the user to treat the entries as if they had "null" values, as is the case for some entries.

For most records, upon replacing the "-1" values by "0" hours, the additive man hour records sum up to the *total man* record. When the values are left as "-1", the records values are no longer additive. The "-1" values may have been an indicator of some specific condition. Unfortunately, there is no documentation to support this hypothesis and no common factor among the events or the subcategories assigned "-1". Where replacing the "-1" entry with a "0" ensures consistency, subcategory values of "-1" have been changed to "0" in the database along with a note explaining the situation. Comments indicating this change have been added to the *Remarks* record in accordance with NaSCoRD QA processes (see Section 3.1).

After adjusting for negative restoration time values, it was discovered that the subcategories of restoration man hours do not always sum to the total restoration man hours. According to the CREDO input guide, the subcategories should sum directly to the total [25, p. 27-28]. This occurred for fifty-five events. Of those:

- Twenty events are missing data for at least one restoration man hour subcategory.
- Ten events have significant round-off error.
- The remaining twenty-five events with "-1" have no obvious cause and require further investigation which will involve a time intensive process of locating and reviewing associated documents for insights.

These event entries have not been altered, as further investigation is required to determine the appropriate action, if any, to be taken.

4 Creation of NaSCoRD

A significant effort undertaken this year was to prepare data from the CREDO-I and CREDO-II databases to be merged into NaSCoRD. The two data tables relating to events and operational history had to be reconciled because both source databases contained sometimes inconsistent entries. Engineering data for components will be added to NaSCoRD largely as it appears in CREDO-I. This section discusses the following topics:

- Section 4.1 describes efforts to bound the starting and ending dates of events in CREDO-II for checking against potential matches in CREDO-I,
- Section 4.2 describes how the event matching was conducted.
- Section 4.3 describes how the operating data in CREDO-I were standardized.
- Section 4.4 describes how the operating information was combined.
- Section 4.5 describes how event records can be mapped to appropriate operating data record in the case of overlapping records.

4.1 Bounding Event Dates

The CREDO-I database included great detail regarding the circumstances of each event, including starting, resolution, and reporting dates. This was not the case for CREDO-II as events were gathered from previously-written reports that were not necessarily intended to be used as records for reliability analysis. Of the 950 events currently in CREDO-II, 826 have well-defined start dates and 205 have well-defined resolution dates. 199 events have both start and resolution dates defined. In most cases, a start date was given but a resolution date was not. The script `all_date_bounds` plots the bounding dates for events with missing dates using outputs from the functions `sfr_doc_bounding` (see Section 4.1.1) and `sfr_hist_bounding` (see Section 4.1.2). Due to the nature of the bounding methods, some events could not be bound within a reasonable time period (see Figure 18 for the distribution of resolution times bound solely on document dating). These were generally cases where an event was mentioned in a report covering many months or years and a resolution date was never given. A cutoff may be specified, such as 70 days in Figure 19, which shows the majority of the events in greater detail. For document date bounding, the period of coverage of the document that mentioned an event was used to limit the duration of an event.

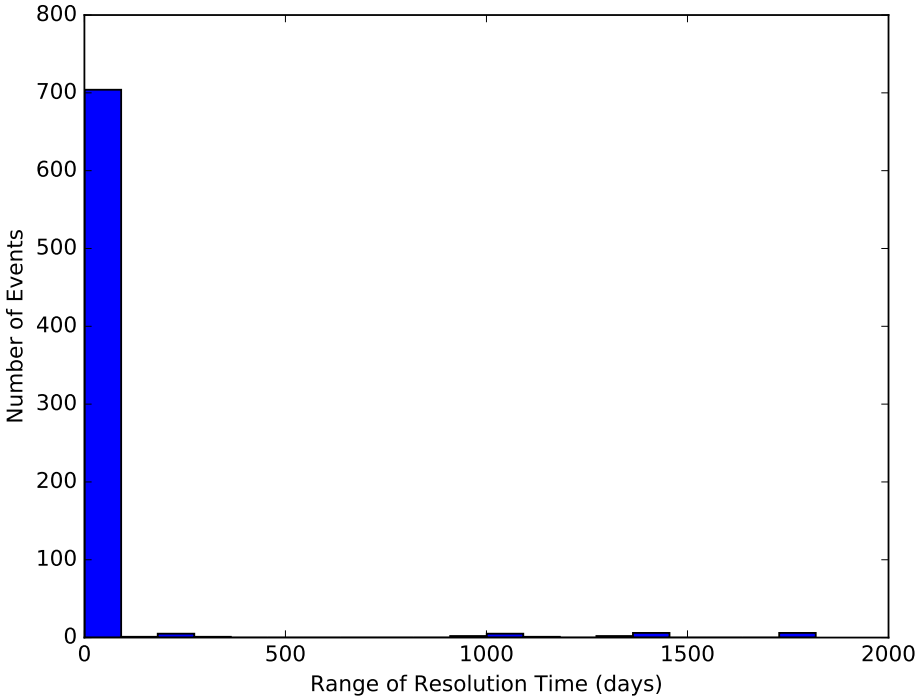


Figure 18: CREDO-II Event Resolution Bounding based on Document Dating.
A zoomed-in view is given in Figure 19.

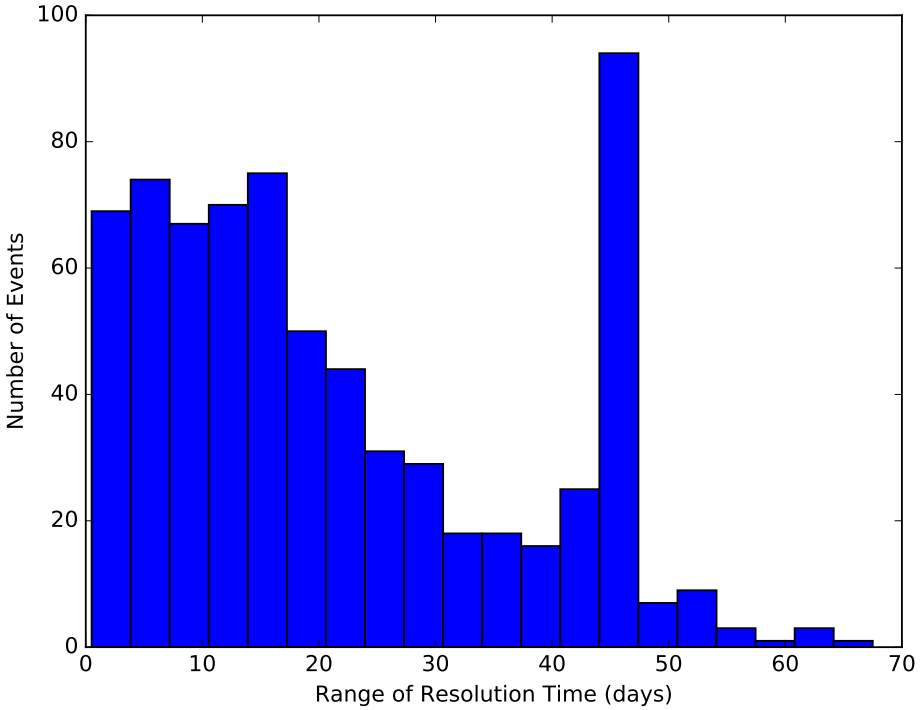


Figure 19: CREDO-II Event Resolution Bounding based on Document Dating, zoomed to 0-70 days

The raw histogram of bounding based on reactor operating history is shaped similarly to that of document bounding with a small number of cases that extend the histogram to cover many years, as seen in Figure 20. In history-based bounding, the reactor power history was used to bound events that required a scram or shutdown. For example, if the resolution date was unknown for such an event, the latest it could have been resolved is the next day the reactor returns to power. More detail can be seen in Figure 21, where only events resolved within 70 days are displayed. There are similarities in the distributions for document-based and history-based bounding, as shown in Figures 19 and 21. This is due to numerous documents being used which were reports of a single run of a research or test reactor. Such reactors were typically powered down in between test runs. In these cases, the coverage period of the document and the period of continuous reactor operation were similar. These bounding ranges may be used in reliability analyses, along with the known duration of similar events, to create estimates of availability for components and systems.

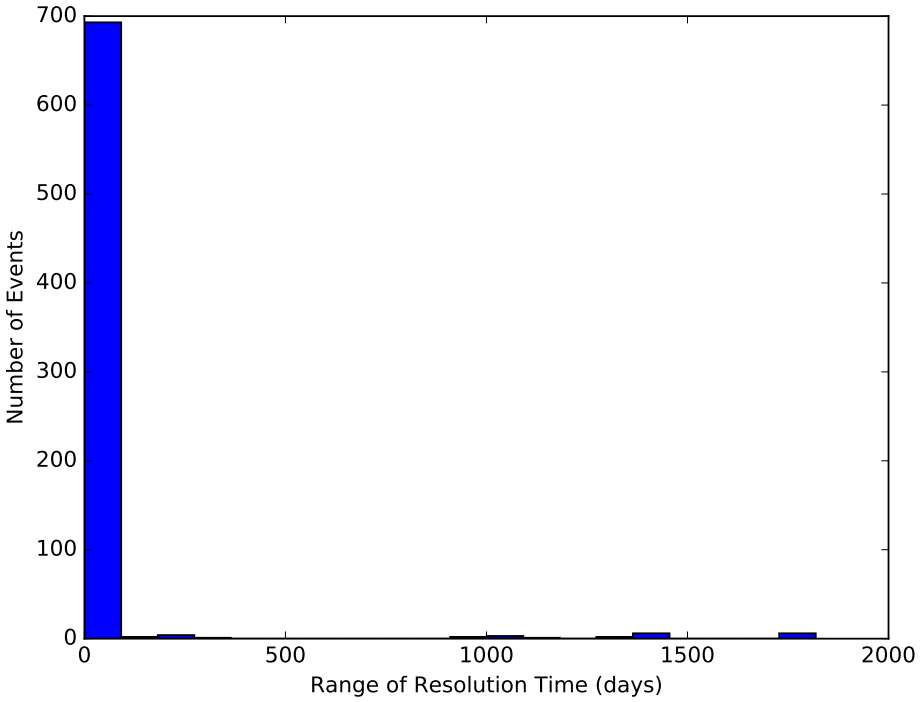


Figure 20: CREDO-II Event Resolution Bounding based on Reactor History.
A zoomed-in view is given in Figure 21.

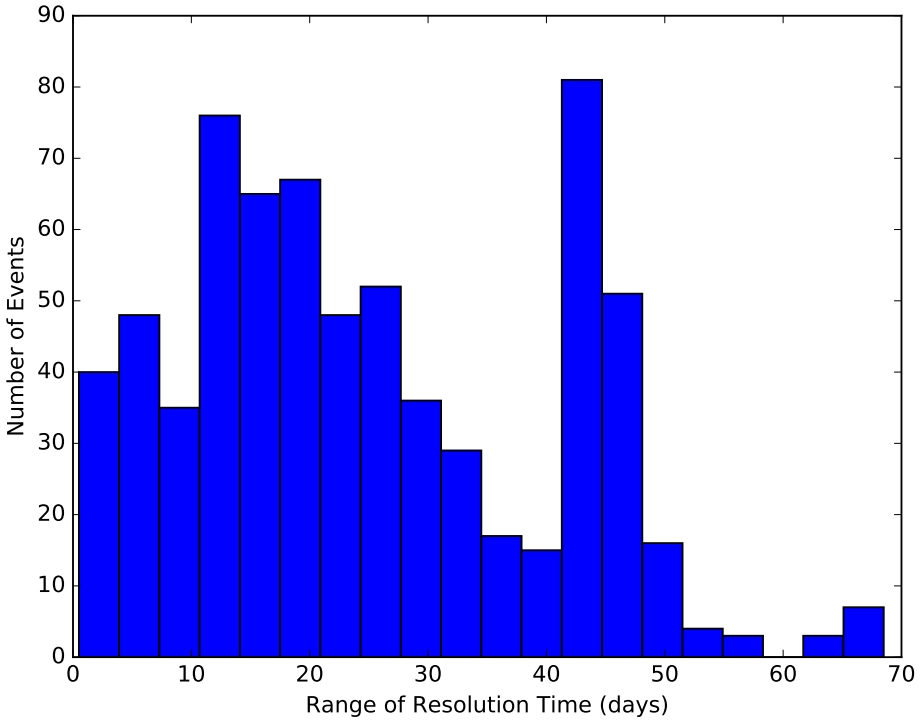


Figure 21: CREDO-II Event Resolution Bounding based on Reactor History, zoomed to 0-70 days

The processes used to bound events and create Figures 18 through 21 are described in Sections 4.1.1 and 4.1.2 for document-based bounding and reactor history-based bounding, respectively.

4.1.1 Bounding Events by Document Dates

Some events in the CREDO-II database do not have defined start or resolution dates. One method to bound missing dates, used in the script `sfr_doc_bounding`, is to use the dates of coverage of the document that describes the event. This is applicable when the description of the event implies that it was resolved. For the start date, the following criteria are used:

- Upper bound will select first day covered by the document.
- Lower bound has the following options:
  - If resolution date given then select the day before the resolution date.
  - If no resolution date given then select the first day covered by the document.

Note that in the case that both the start and resolution dates are missing, the start date is assumed to be the first day of coverage of the document. For the resolution date, the following criteria are used:

- Upper bound will select the last day covered by the document.
- Lower bound has the following options:
  - If a start date is given then select the day after the start date.
  - If no start date is given then select the second[2] day covered by the document.

Using document bounding, all events could be given a range of start and resolution dates. For the resolution date of events (not including those that are already defined), the median uncertainty between the upper and lower bounds was 18 days, which was considered reasonable as most documents covered slightly less than a month of time. The maximum uncertainty was 1,819 days for a number of events mentioned in a report that covered multiple years. The median uncertainty for the start dates of events, excluding those that are already defined, was 18.5 days with a maximum of forty-one days.

4.1.2 Bounding Events by Reactor History

For events that required a shutdown or scram of the reactor, timing may be bound using the reactor history power, as used in the script `sfr_hist_bounding`. A shutdown or scram was required for 365 events, 307 of which had uncertain resolution dates. Only two of the 365 events were missing the start date. Most reactor run logs for EBR-II provided daily history of the number of critical hours and the maximum and minimum thermal powers reached. If an event caused shutdown and required that the reactor remain shut down during repair, its resolution date can be bound by the next day the reactor produced power[3]. The daily history of the reactor for the time period covered by the document mentioning the event is assembled in order and days are categorized as reactor operation and reactor downtime days.

For the start date of the event, the following criteria are used:

- Upper bound will select the last day of the first period of continuous operation.
- Lower bound will select the last day of the last period of continuous operation.

For the upper bound of start date, the first transition from reactor operation to downtime covered by the report is found. The last day with some operation before that transition is used as the start date. The lower bound of the start date is the last operational day in the record. The upper bound of the resolution date uses the last day in the record. The lower bound uses the next day the reactor ran after the start date, if such a date occurred within the record:

[2]The second day covered by the document was chosen as a realistic compromise, as most events in CREDO-II that have defined start and end dates required a day or more to resolve.

[3]Care must be taken to ensure that the reactor was not restarted without returning the component to service.

- Upper bound will select the last day covered by the document.
- Lower bound has the following options:
  - If reactor returned to power after start date then select the first day of continuous operation after start date.
  - If reactor did not return to power after start date then select the last day covered by the document.

Using reactor history-bounding yielded a range of resolution dates for 287 events out of 307 that required scram or shutdown and had uncertain resolution dates. The median range for resolution was 19 days.

4.2 Matching CREDO-I and CREDO-II Events

Due to overlaps in facility coverage for EBR-II and FFTF, CREDO-I and CREDO-II are believed to describe many of the same failure events. The script `sfr_event_matching` is an interactive tool used to identify potential matches and present them in a user-friendly manner to be confirmed, denied, or left uncertain. The process may be repeated using the output from the previous iteration as an input, and matches that are confirmed or denied are not displayed a second time. Because information is continuously gathered, this allows the user to come back to a potential match that has previously been left uncertain with new insight and either confirm or deny that it represents an overlapping event. Matches (with relevant event identification numbers) are noted in the affected CREDO-I and CREDO-II entries, as well as in NaSCoRD.

Sets of events are presented to the user which affect the same facility and have other similarities. The first set of events are those that affect the same facility and have identical event start dates. In the case of undefined CREDO-II start dates, the middle of the bounding range (see Section 4.1) is used, and so an exact match is unlikely (see below for additional step with wider matching range). The user is presented with the following records side-by-side from each database:

- *Start date*
- *Resolution date*
- *Affected system*
- *Affected component*
- *Event narrative*

Given this information, the user is asked to confirm or deny a match. The user may also skip the potential pair or return to the last potential pair to re-evaluate the choice made. Multiple CREDO-I

events may be associated with a single CREDO-II event, because in some cases multiple CREDO-I reports were filed as a failure was discovered, diagnosed, and resolved over time. The method that only allows matches based on an exact match of start date returned seventy-two potential matches between the databases. The next method used was to evaluate events with the CREDO-I start date within three days of the CREDO-II start date or within the bounding range. This method resulted in 219 potential matches. Between the two methods, seventy-six CREDO-I events have been matched to sixty-six CREDO-II events. These event pairs will be combined into single entries in NaSCoRD with the process represented by *Reconcile Overlapping Entries* in Figure 3. There are hundreds of events in both CREDO-I and CREDO-II that have not been identified as matching.

4.3 Standardizing CREDO Operational Data

The three CREDO-I operational output data records, *design output*, *authorized output*, and *total report period output*, used a variety of units, as written in [8]:

> Output units depend on type of facility and are specified by mutual agreement of CREDO and site staffs.

Rather than including separate records with units, the units were standardized. If a future facility requires another physical measure to represent its output, such as flow, this decision may be revisited.

Design Output

The *Design Output* record in CREDO-I refers to the designed capacity of the facility, which may be reduced for certain experimental configurations (see Section 4.3). The original units included MWt, MWt-hr, daWt (dekawatts thermal), MWe, and hours. This record was standardized to MWt.

The original units were ascertained using a combination of the CREDO-I comments, knowledge of the operating parameters of the facility, and testing of potential units for logical consistency with the operating hours. For example, one facility that was known to have a 1 MWt heat source used "100000" for every Design Output entry. The use of a consistent value across entries with varying time intervals suggested that the parameter was a level of some kind, rather than a theoretical cumulative measure. For facilities with varying Design Output, dividing the Design Output by the operating hours often yielded a consistent power level, revealing that the initial entry was the theoretical cumulative energy output.

Authorized Output This Period

The *Authorized Output This Period* record in CREDO-I represents the facility capacity for the period in question. In many cases it was equal to the *Design Output*. A notable exception is FFTF,

where in 1987 the core was reconfigured as the Core Demonstration Experiment [26] and the rated power reduced from 400MWt to 291MWt. Original units included MWt, MWt-hr, daWt, hours, and effective full power days. This field was also standardized to MWt.

The Authorized Output units were also determined using a combination of the CREDO-I comments, knowledge of the operating parameters of the facility, and testing against operating hours. Authorized Output was more likely than Design Output to be a theoretical cumulative energy output, which was discovered by dividing the value by the operating hours. In most cases, aside from later operation of FFTF, after adjustment this value either matches the Design Output or is zero.

Report Period Total Output

The Report Period Total Output in CREDO-I represents some measure of accumulated facility output during the specified time period. For reactors, it generally measures the reactor thermal or electrical output and varies closely with *Operating Mode 1* (*Power Operations*) time (see Section 3.2.3). For other test facilities, the output often represents the energy consumption of a heater, and increases during both *Operating Mode 1* (*Isothermal Operation*) and *Operating Mode 2* (*Transitions* or *Hot Standby*). Original units included MWt-hr, MWe-hr, daWt-hr, hours, and effective full power days. This field was standardized to MWt-hr.

4.4 Combining Operational Data

Facility operating information is provided in both databases in a variety of time intervals. Such information was typically provided on the basis of a month, a quarter, or an experimental "run" of the reactor in CREDO-I as well as the logs obtained for CREDO-II. Daily information is currently available in CREDO-II for most days for EBR-II but not at all for other facilities.

Each entry in the operating information table in CREDO-I provides the following numerical records over an interval of dates, the meanings of which were determined using the processes in Sections 3.2.2 and 3.2.3:

- *Operating Time, Mode 1* (hr)
- *Operating Time, Mode 2* (hr)
- *Operating Time, Mode 3* (hr)
- *Design Output* (units vary)
- *Authorized Output This Report Period* (original units varied, standardized to MWt)
- *Report Period Total Output* (original units varied, standardized to MWt)

Depending on the facility and the reporter, units varied substantially for the output in CREDO-I. These were standardized as described in Section 4.3. The entries in CREDO-II provide the following numerical records:

- *Critical Time* (hr)
- *Cumulative Critical Time* (hr)
- *Generator Time* (hr)
- *Cumulative Generator Time* (hr)
- *Thermal Energy* (MWt-hr)
- *Cumulative Thermal Energy* (MWt-hr)
- *Electrical Energy* (MWe-hr)
- *Cumulative Electrical Energy* (MWe-hr)
- *Maximum Thermal Power* (MWt)
- *Minimum Thermal Power* (MWt)

The script `nascord_operating_data_gather` was written to combine operational data from both databases for NaSCoRD. No data were discarded, although overlaps in coverage required the development of a method to assign priority to data sources for use in reliability calculations (see Section 4.5). The CREDO-I *Operating Time, Mode 1* and CREDO-II *Critical Time* records were combined as they had equivalent meaning for the facilities included in CREDO-II. No other combinations were possible as fields had the potential to vary significantly between reactors and test loops.

4.5 Prioritizing Operational Data

The operational data in CREDO-I were entirely interval-based, while those in CREDO-II were either interval-based or provided for a single day. Once data were combined as described in Section 4.4, some days were covered by multiple entries. Because the entries were not always in agreement, record prioritization was required. The script `nascord_interval_operating_data` returns operational data for a specified time interval and a specified facility by performing interpolation between the start and end dates of a database entry if required. This requires prioritization of the data, and the script includes flexible parameters to choose a preferred data source, i.e., CREDO-I vs CREDO-II.

The script `nascord_interval_operating_data` steps through each date in the requested interval and determines how many entries cover it. If there is only one entry, it is interpolated from its full

span down to the day. When multiple entries exist, the chosen prioritization scheme is applied. By default the script assumes the philosophy of Occam's razor which proposes that the simplistic hypothesis should be taken unless there is justification for additional complexity. NaSCoRD will enact the minimal interpolation possible for each entry in question. For example, a daily reactor history entry is preferred by default because no interpolation is required. The preference is only used to resolve conflicts: if the preferred data source (CREDO-I vs CREDO-II) does not cover a day within the specified interval but the other does, the script uses the non-preferred source if it covers that day.

The fact that interpolation occurred and the method of interpolation used is recorded in the NaSCoRD database. If these modified records are used in reliability calculations, the final NaSCoRD database will warn the user of this fact and allow the user to utilize a different interpolation method or to treat such entries as though they had "null" values.

5 Interface for External Users

An access-controlled web-based interface to the SRDs is being developed by SNL in order to support both the needs of the sodium reactor industry and development efforts within the national laboratory complex. The following subsections describe this web-based interface:

- Section 5.1 describes how users can both request and obtain access to the CREDO-I and CREDO-II database.
- Section 5.2 explains the type of content found on the SRD website.
- Section 5.3 summarizes additional capabilities available to SNL developers that can be used to create, improve, or customize future reporting.
- Section 5.4 proposes a future for the SRD website.

5.1 Gaining External User Access on the Sandia External Collaborative Network

Access to the data inside the SRDs is limited. The facility operational data was primarily generated by Atomic Energy Commission (AEC), and subsequently DOE, funded test facilities. As a result, DOE approval is required for access to the source data. The proper DOE contact for approval is the DOE:NE ART sodium program manager, Thomas Sowinski (Thomas.Sowinski@Nuclear.Energy.Gov) at the time of publication. Once DOE has granted the requester approval to the SRDs the SNL project manager, Matthew Denman (Matthew.Denman@Sandia.Gov) at the time of publication, will arrange the creation of an External Collaborative Network (ECN) account[4]. Next, the requester's ECN account will be provided access to the SRD website[5]. Account access can be segmented to restrict access to export controlled and/or legacy Applied Technology (AT) reports. Personnel who are granted access to the SRD website are expected to be given access to all associated documents. Periodic public summary publications will be produced to provide key insights resulting from the database and will be available to those without direct access to the SRD website.

5.2 Contents of the Sodium Reliability Database Website

The SRD website (see Figure 22) has multiple features that can support the engineering of future sodium systems including both test loops and reactors. The SRD website is under development

[4]Creation of an ECN account requires the requester to provide SNL with sensitive personal information and take periodic SNL cyber-security training.

[5]Access to SNL systems and the SRD website is subject to US law and SNL corporate policy

and subject to change. It currently contains the following information to support both engineering/safety assessments and PRAs:

- Section 5.2.1 explores the CREDO-I reports[6].
- Section 5.2.2 explores the CREDO-II reports.
- Section 5.2.3 describes how supporting documents, e.g., run logs, cycle reports, and Unusual Occurrence Reports (UORs), are sorted and stored.
- Section 5.2.4 presents the image database for structures, systems, and components of CREDO related systems.
- Section 5.2.5 proposes a future capability for incorporating new sodium test loops into the NaSCoRD database.
- Section 5.2.6 shows the report page where engineering system or component summaries will be stored.

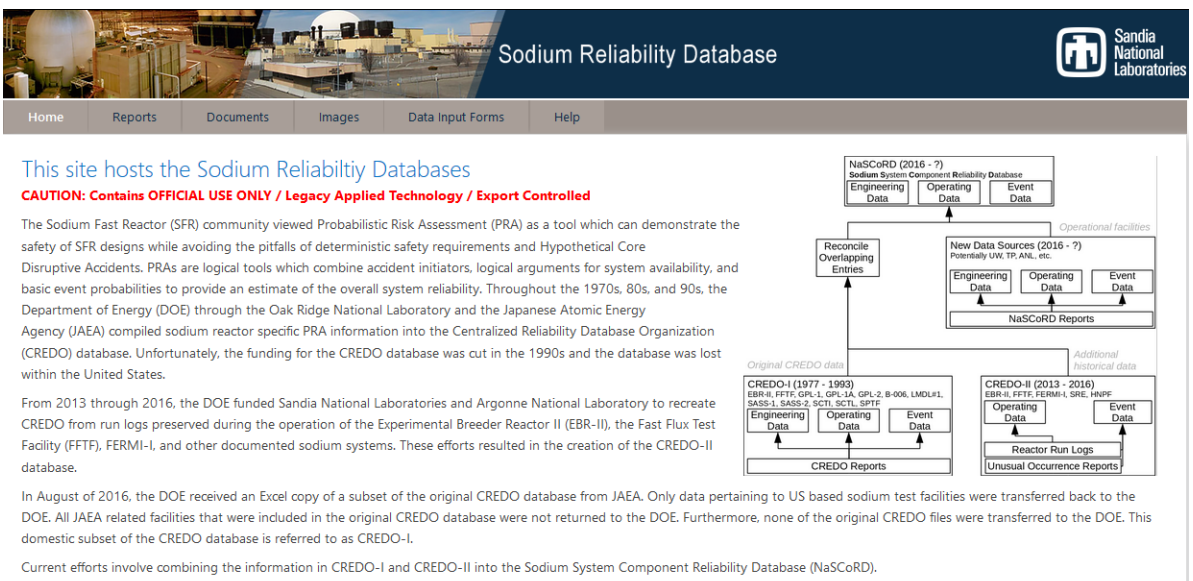


Figure 22: Screen-shot of the SRD Home Page

5.2.1 CREDO-I Reports

The CREDO-I reports are found under the reports tab as shown in Figure 23. The CREDO-I reports consist of the CREDO data-sheets provided by JAEA in August of 2016 [4]. The reported data have been reformatted for readability but have not been modified unless there was an obvious error (see Section 3). The three CREDO-I reports are:

[6]See Section 1.1 for the definitions of Reports, Records, and Entries.

- Section 5.2.1.1 presents the operating records for CREDO-I facilities.
- Section 5.2.1.2 presents the engineering records for CREDO-I facilities.
- Section 5.2.1.3 presents the event records for CREDO-I facilities.

The Help tab found on the SRD website provides the definitions of key records for the three reports.

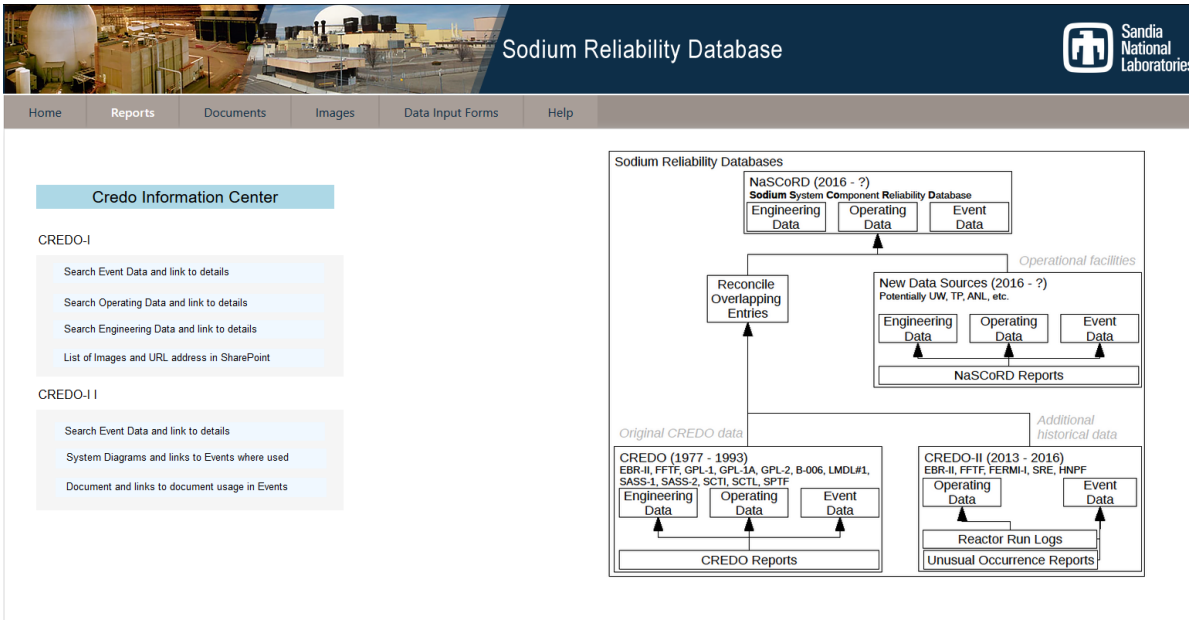


Figure 23: Screen-shot of the SRD Reports Page

5.2.1.1 CREDO-I Operating Report

The operating reports store the operating history for every unit included in the CREDO-I database. The CREDO-I operating reports were submitted to ORNL when the facility completed a quarterly reporting period.

To improve the readability of the database, the operating data report was broken into two layers. The first layer contains a summary list of the site-unit, report period, unit design output, unit maximum allowable output, and optional comments about the reporting period. This level is intended to allow the user to quickly sort through the report for the subset of data. The user can sort the report by *Unit*, *Report Period*, *Design Power level*, *Authorized Output This Period*, and *Total Output This Period*. The first level report layout is shown in Figure 24. Content is presented in sortable columns and content filters are provided on the right side of the screen.

The entire operating data record for a given unit is presented in the second level. The operating information is broken into five categories which were preserved from the original CREDO database. Records which were left blank are either not applicable to the unit or were left incomplete from

the original database[7]. The second level report layout is shown in Figure 25 with the report text redacted to protect sensitive information.

The records included in the detailed reports page are:

1. Report Identification This record includes record *ID*, the *Site - Unit*, and reporting periods and dates.

2. Operating Times This record includes the hours the unit spent in *Mode 1*, *Mode 2*, and *Mode 3* that are needed to perform the time and cycle to failure calculations in Equations 3 and 4 shown in the records 5 and 6 of the Engineering Reports described in Section 5.2.1.2.

3. Facility Availability Data This record includes the *Design Output*, *Authorized Output This Period*, and information regarding expected and forced outages during the reporting period.

4. Signatures This record provides a log of the individuals who modified the entries in this report. When SNL's development team notices an error in the CREDO-I entries, the SNL developer who updates the CREDO-I entry is appended here.

5. Events During Operating Period This new field provides a summary of events (see Section 5.2.1.3) that occurred at the selected unit during the selected reporting period.

[7]The blank records are an intermediate step while SNL developers compile a definitive list of entries for a given record. Once this list is compiled, blank records will be replaced with entries stating that the record was incomplete. Irrelevant entries will be removed from the report.

CREDO-I Operating Data Summary and Search

Page 1 of 1

Number of Rows Retrieved: 408

ID	Site - Reactor	Report Year - Quarter		Report Period Start Date	Report Period End Date	Report Date	Design Output	Authorized Output This Period	Total Output This Period	Comments or Discussion
1	ANL - EBR-II	1964 - 3	Details	1964-07-01	1964-09-30	1979-12-06	62.50	0.00	[redacted]	Maximum output power was 30 mwt. ebr-ii initial criticality for "approach to power" was o electric power produced from nuclear power was on 8/7/64.
2	ANL - EBR-II	1964 - 4	Details	1964-10-01	1964-12-31	1979-12-06	62.50	0.00	[redacted]	Maximum output was 37.5 mwt.

Parameters

Select Site - Reactor(s)

ANL - EBR-II, ETEC - B-006, ETE

Select Report Period Year(s)

1964, 1965, 1966, 1967, 1968, 1

Figure 24: Screen-shot of the CREDO-I summary operating reports page.
Some content is redacted to protect the trade value of the database.

CREDO-I Operating Data Detail

1. REPORT IDENTIFICATION

ID	Site - Unit	Site Name	Reactor/Unit Name	Credo Report ID	Report Period Year	Quarter	Report Period Start Date	Report Period End Date	Report Date
56	ANL - EBR-II	ARGONNE NATIONAL LABORATORY	EXPERIMENTAL BREEDER REACTOR 2	[redacted]					

2. OPERATING TIMES

Mode 1 Hours	Mode 2 Hours	Mode 3 Hours
1,453.0	647.0	84.0

3. FACILITY AVAILABILITY DATA

Design Output	Authorized Output This Period	Total Output This Period	Scheduled Outages (Number)	Scheduled Outages (Hours)	Unschedule Outages (Number)	Unschedule Outages (Hours)
62.5	0.0	24,280.0				

Transients or Cycles (Number)	Transients or Cycles(Hours)	Comments / Discussion
N/A	N/A	N/A

4. SIGNATURES

Writer or Registrant
HUDSON, S.D. 574-5288

5. EVENTS DURING OPERATING PERIOD

⊟ Expand To View

Event Date & Time		System	Component	Occurrence Title
[redacted]	View Details	IMPURITY MONITORING AND ANALYSIS SYSTEM	GAS MOVERS	[redacted]
	View Details	GAS COOLING SYSTEM	GAS MOVERS	

Figure 25: Screen-shot of the CREDO-I detailed operating reports page.
Some content is redacted to protect the trade value of the database.

5.2.1.2 CREDO-I Engineering Report

The engineering reports store design information about the requirements, operating environment, and expected performance of every component included in the CREDO-I database. The CREDO-I engineering reports were submitted to ORNL when a given component was placed in service at a facility and were updated again when the components were removed from service.

To improve the readability of the database, the engineering data report was broken into two report layers. In the first layer a summary list of the CREDO-I *ID*, the *Site - Unit*, *System*, *Subsystem*, *Component*, the component number or *CID_Number*, *Date Installed and Removed*, and the number of events associated with the component are presented. This layer is intended to allow the user to quickly sort through the report for the subset of data. The first layer report layout is shown in Figure 26. Content is presented in sortable columns and content filters are provided on the right side of the screen. A hyperlink is provided under the report date column to view the second layer of report information for the selected record.

The entire engineering data record for a given component is presented in the second layer. The component information is broken into ten categories which were preserved from the original CREDO database. Records which were left blank are either not applicable to the component or were left incomplete from the original database[8]. The second layer report layout is shown in Figure 27 with the report text redacted to protect sensitive information.

The categories included in the detailed reports page are:

1. Report Identification This record includes high level summary information for the component report. Key information for this record includes:

- CREDO and CREDO-I report numbers,
- *Site* and *Unit* information, and
- *Report date* and version information.

2. Component Identification This record includes unique identification information for the component. Key information for this record includes:

- component and site information, including the component *Name*, the *CID Number* which is unique within a given unit but not between units, the *Site ID Number*, component model number, vendor and drawing number,

[8]The blank records are an intermediate step while SNL developers compile a definitive list of entries for a given record. Once this list is compiled, blank records will be replaced with entries stating that the record was incomplete. Irrelevant entries will be removed from the report.

- component safety class information, including whether the component is part of the plant protection system, consensus codes and standards applied to the component, and the required safety or quality class, and
- usage information, including when it was installed, removed, and if it was used beyond its designed range.

Component drawings are not currently available to the development team. If these drawings become available in the future, they will be hyper-linked to this screen.

3. Component Description This record includes operational descriptions of the component. For all component types the first field describes the specific type of component within the component record used, while subsequent records vary according to the type of component being described, as defined in Table 10.

4. Component Use and General Design Information This record includes location and design life information, if available, including:

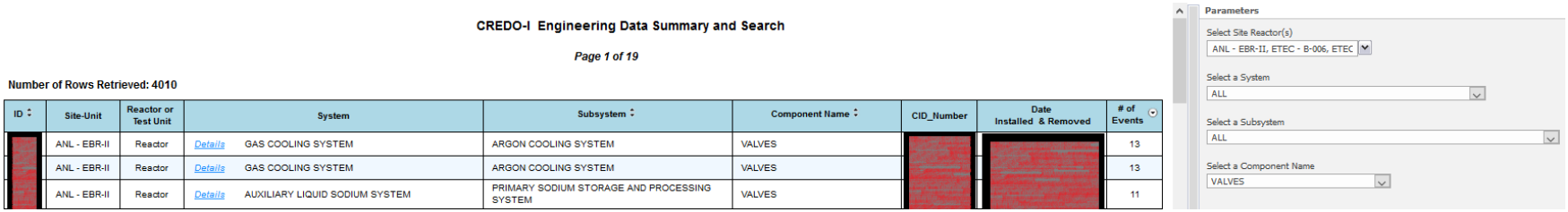
- *System* and *Subsystem* in which the component is located,
- a description of what function the component is trying to perform and its general application, e.g., reactivity control, and
- the number of hours or cycles the component was designed to survive.

For directions on accessing component failure information in the event report, see Section 5.2.1.3.

5. Operating Factor This record includes the expected percent of time the component would operate while a facility is in a given mode of operation. This information is combined with the facility operational history described in Section 5.2.1.1 to calculate the operational hours until failure of a component using Equation 3:

$$T = \frac{T_1 * OF_1 + T_2 * OF_2 + T_3 * OF_3}{100} \tag{3}$$

where T is the component operating time, T_1, T_2, and T_3 are the time periods in hours that the facility spends at in modes 1, 2, and 3 respectively, and OF_1, OF_2, and OF_3 are the operating factors, in percent, for modes 1, 2, and 3 respectively. The definitions for mode 1, 2, and 3 are conditional on the type of facility and can be found in Table 8. The number of hours before component failure is used in Equation 1 to calculate the failure frequency of the component.



CREDO-I Engineering Data Summary and Search

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Number of Rows Retrieved: 4010

ID	Site-Unit	Reactor or Test Unit	System	Subsystem	Component Name	CID_Number	Date Installed & Removed	# of Events
[redacted]	ANL - EBR-II	Reactor	Details GAS COOLING SYSTEM	ARGON COOLING SYSTEM	VALVES	[redacted]	[redacted]	13
[redacted]	ANL - EBR-II	Reactor	Details GAS COOLING SYSTEM	ARGON COOLING SYSTEM	VALVES	[redacted]	[redacted]	13
[redacted]	ANL - EBR-II	Reactor	Details AUXILIARY LIQUID SODIUM SYSTEM	PRIMARY SODIUM STORAGE AND PROCESSING SYSTEM	VALVES	[redacted]	[redacted]	11

Figure 26: Screen-shot of the CREDO-I summary engineering reports page.
Some content is redacted to protect the trade value of the database.

Table 10: Changing Field Definitions for Engineering Report Component Descriptors

Component	Record 2	Record 3	Record 4	Record 5	Record 6	Record 7	Records 8-10
Annunciator Alarm Modules	Alarm	Alarm Fail Safe	Function on Loss of Normal Power	Alarm Redundancy	Alarm Redundancy	Parameter Indicated	N/A
Batteries	Application	Electrode Type	Class	Replenish Electrolyte Level Period	N/A	N/A	N/A
Circuit Breaker and Interrupters	Closure	Cooling and Arc Quenching	AC Phase Type	Contact Sets	Actuation	Grounding	N/A
Cold Traps and Vapor Traps	Medium Processed	Cooling Medium	Passes Per Cycle	Vapor Entrapment	Heat Exchanger	Trap Material	Shell Body Material
Contactors and Starters	Driver Actuation	Actuation Current	Cooling and Arc Quenching	Closure	AC Phase Type	Contact Sets	Grounding

continued . . .

Table 10 (continued) Changing Field Definitions for Engineering Report Component Descriptors

Component	Record 2	Record 3	Record 4	Record 5	Record 6	Record 7	Records 8-10
Control Rod Drive Mechanisms	Connection to Control Rod	Rod System	Connection Mode	SCRAM Potential	Control System Requires External Flow Pressure	Disengagement Mode	N/A
Electrical Buses	Location	Closure	Conductor	Phase	Bus Material	Insulation Material	N/A
Electrical Conductors	Terminal Type	Jacket Material	Conductor Material	Circuit Voltage and Amperage	Wire Insulation	N/A	N/A
Electric and Electronic Connectors	Signal Channels	Grounding	Environmental Use	Construction Type	N/A	N/A	N/A
Electrical Heaters	Function	Heater Form	Heater Application	Heat Distribution	Control	Power	Duty Cycle
Electro-Magnetic Pumps	Seals	Mounting Axis	Medium Processed	Driver Power	Pump Duct Material	Bus Material	N/A
Filters Strainers	Medium Processed	Filter Mechanism	Driver Mechanism	Filter Material	Body Material	N/A	N/A
Fuses	Application	Design	Circuit Power	N/A	N/A	N/A	N/A
Gas Dryer	Medium Processed	N/A	N/A	N/A	N/A	N/A	N/A
Gas Mover	Design Type	Driver	Gas Type	N/A	N/A	N/A	N/A
Generators	Output	Driver Type	Output Current Phase	Application	Facility Safety Trip	N/A	N/A
Heat Exchangers	Design Type	Medium Processed	Configuration	Primary Flow Side	Shell Material	Tube Material	Heating or Cooling Agent

continued . . .

Table 10 (continued) Changing Field Definitions for Engineering Report Component Descriptors

Component	Record 2	Record 3	Record 4	Record 5	Record 6	Record 7	Records 8-10
Indicators	Parameter Indicated	Operational Principle	Form of Output Data	N/A	N/A	N/A	N/A
Instrument Controllers	Operational Function Type	Controlled Parameter	Master Control Sensing	Controller Driver	N/A	N/A	N/A
Internal Combustion Engines	Block	Cycle	Fuel	Application	Duty Cycle	Starting	8. Position 9. Cooled 10. Control
Liquid Rheostats	Function	Control Applications	Cooling	N/A	N/A	N/A	N/A
Logic Gates	Function	Input Signal Type	Design Type	Gate Fail Mode	N/A	N/A	N/A
Mechanical Control Devices	Operational Character-istics	Driven by	Controlled Parameter	Application	Control Function	Control	N/A
Mechanical Pumps	Driver	Speed Controller	Mounting Axis	Medium Pumped	Shaft Seal In-Fluid	Impeller	8. Impeller Material 9. Casting Material
Motors	Duty Cycle	Phase	N/A	N/A	N/A	N/A	N/A
Non-Nuclear Sensors	Medium Monitored	Use Cycle	Sensing Element Type	N/A	N/A	N/A	N/A
Nuclear Detectors	Radiation Detected	Primary Function	Signal Modification	Sensitive Element	Signal Type for Analysis	Reactor SCRAM or Trip	Flux Monitoring Range
Penetrations	Design Type	N/A	N/A	N/A	N/A	N/A	N/A
Pipe and Fittings	Medium Processed	Pipe Schedule	Basic Materials	N/A	N/A	N/A	N/A

continued . . .

Table 10 (continued) Changing Field Definitions for Engineering Report Component Descriptors

Component	Record 2	Record 3	Record 4	Record 5	Record 6	Record 7	Records 8-10
Plugging Meters	Medium Processed	Cooling Medium	Heat Exchanger	Plugging Element Material	N/A	N/A	N/A
Power Supplies	Design Type	Output Voltage Quality	Grounding	Polarity	Unit Location	Input	Output
Pressure Vessels and Tanks	Shape	Medium Processed	Tank Basic Material	Tank Liner Material	N/A	N/A	N/A
Reactor Control Rods	Application	Poison Material	Mounting Axis	Environmental Media	Poison-Fueled Follower	Rod System	Cladding Material
Recombiners	Inerting Agent	Medium Processed	Major Component Material	N/A	N/A	N/A	N/A
Recorders	Input Signal Type	Recording Mode	Contacts for Functional Response	N/A	N/A	N/A	N/A
Relays	Design Type	Coil Voltage Type	Coil Status	Contact Voltage Type	Closure	Application	N/A
Rupture Devices	Medium Processed	Type Attachment	Activator	N/A	N/A	N/A	N/A
Signal Modifier	Function	Output Signal Routing	Design Class	N/A	N/A	N/A	N/A
Signal Transmitter	Driver Design	Output Signal	Input Sensor	Signal Transmitted By	N/A	N/A	N/A

continued . . .

Table 10 (continued) Changing Field Definitions for Engineering Report Component Descriptors

Component	Record 2	Record 3	Record 4	Record 5	Record 6	Record 7	Records 8-10
Support and Shock Devices	Function	Support Method	Attachment	Note: No Type Record for this Component. Only three records are provided.			
Switches	Environmental Medium	Design Type	Application	N/A	N/A	N/A	N/A
Transformers	Closure	Cooling	Usage	Status	N/A	N/A	N/A
Turbines	Stage	Form	Flow	Turbine Blading	Generator Coupling	N/A	N/A
Valves	Functional Application	Functional Character-istics	Medium Processed	N/A	N/A	N/A	N/A

CREDO-I Engineering Data Detail

1. REPORT IDENTIFICATION

ID	Site	Unit	Credo Report ID Number	Report Date	Version	Previous Report Date
2773	WESTINGHOUSE ADVANCED REACTORS DIVISION	GENERAL PURPOSE LOOP-1	[redacted]	1982-08-18	0	

2. COMPONENT IDENTIFICATION

Name	CID Number	Site ID Number	Plant Protection System (Y or N)	Model No.	Vendor	Drawing Number	Date Installed	Date Removed	Standard or Code	Safety or Quality Class	Extention Design Extension Usage
PIPE AND FITTINGS	[redacted]										

3. COMPONENT DESCRIPTION

Type	Functional Application	Functional Characteristics	Medium Processed	Primary Seal	Operator Type	Valve to Pipe/ Equipment Connection	Seal Material	Body Material	Pipe Material	Seat Material	Valve Operatior Controller
[redacted]											

4. COMPONENT USE AND GENERAL DESIGN INFORMATION

System	Subsystem	Design Function	Application	Design Life (hours)	Design Life (Cycles)
LIQUID METAL TEST APPARATUS	LIQUID METAL CIRCULATION	[redacted]			

5. OPERATING FACTOR (% of Time Operating in Each Mode)

Power Operation	Hot Standby	Cold Shutdown
100	100	0

6. DUTY FACTORS (Operational Cycles per Hour)

Power Operation	Hot Standby	Cold Shutdown
0	0	0

7. RADIATION EXPOSURE

Neutron Flux Level (neutrons/cm2sec)

8. MAINTENANCE AND INSPECTION / TEST DATA

Maintenance Interval and Type	Inspection or Test Interval and Type
[redacted]	

9. REDUNDANT REPLICATE COMPONENTS

Redundant Replicate Components

10. REMARKS, SPECIAL INFORMATION

Comment / Discussion
[redacted]

11. SIGNATURES

Writer or Registrant
EICHER, R.L.

12. IMAGES

Available Image(s)
None

13. EVENTS FOR THIS COMPONENT

⊟ Expand (+) To View 1 Event(s)

Event Date & Time	Component Description	Occurrence Title
2/23/1977 4:00:00 PM View Details	[redacted]	

Figure 27: Screen-shot of the CREDO-I detailed engineering reports page.
Some content is redacted to protect the trade value of the database.

6. Duty Factor This record includes the expected number of cycles the component would operate while a facility is in a given mode of operation. This information is combined with the facility operational history described in Section 5.2.1.1 to calculate the number of demands before failure of a component using Equation 4:

$$D = \frac{T_1 * DF_1 + T_2 * DF_2 + T_3 * DF_3}{T_1 + T_2 + T_3} \tag{4}$$

where D is the expected number of component cycles in the time period, T_1, T_2, and T_3 are the time periods in hours that the facility spends at in modes 1, 2, and 3 respectively, and DF_1, DF_2, and DF_3 are the duty factors, in demands per hour, for modes 1, 2, and 3. The definitions for mode 1, 2, and 3 are conditional on the type of facility and can be found in Table 8. The number of demands experienced before component failure is used in Equation 2 to calculate the per-demand failure probability of the component.

7. Radiation Exposure This record provides the neutron flux levels under which the component was exposed. Other radiation types, such as gamma flux, were not recorded.

8. Maintenance and Inspection/Test Data This record provides the frequency and type of maintenance, inspection, and/or testing of the component. These records were not standardized and thus were not used in CREDO to adjust failure rate predictions based on failure types.

9. Redundant Replacement Components This record lists other components in the same unit/system/subsystem set that perform the exact same function. Examples include pumps on different legs of the Intermediate Heat Transfer System (IHTS) or standby equipment.

10. Remarks, Special Information This record provides an opportunity to capture additional information about the component of interest that was not otherwise captured in the detailed engineering data record.

11. Signatures This record provides a log of the individuals who modified the entries in this report. When SNL's development team notices an error in the CREDO-I entries, the SNL developer who updates the CREDO-I entry is appended here.

12. Images This record provides links to images that correspond to the component. In the long term, these images will include Piping and Instrumentation Diagrams (P&IDs) and other schematics. No images where provided with the CREDO-I database and as such this field is still under significant development.

13. Events for this Component This new field provides links to the associated event reports for this component (see Section 5.2.1.3). Multiple event reports would be generated due to a component failing, being brought back into service, and then failing again. By examining all event reports for a component the user can identify common failure modes for a given piece of equipment.

5.2.1.3 CREDO-I Event Report

The event reports store the failure and maintenance event reports for every unit included in the CREDO-I database. The CREDO-I event reports were submitted to ORNL when the facility completed maintenance to a component.

To improve the readability of the database the event data report was broken into two layers. The first layer contains a summary list of the *Site-Unit*, *Event Date and Time* when the record was generated, *Event Title and Report* (which includes any associated document numbers), and a *System/Subsystem/Component* classification. This layer is intended to allow the user to quickly sort through the report for the subset of data. The first layer report layout is shown in Figure 28. Content is presented in sortable columns and content filters are provided on the right side of the screen. Some event rows in the report reference external documents that can provide additional context to the event. A hyperlink is provided under the *Event Year - Quarter* column to view the second layer of report information for the selected record.

The entire event data record for a given unit is presented in the second report layer. The event information is broken into eleven record groups which were preserved from the original CREDO database. Records which were left blank are either not applicable to the unit or were left incomplete from the original database[9]. The second layer report layout is shown in Figures 29 and 30 with the report text redacted to protect sensitive information.

[9]The blank records are an intermediate step while SNL developers compile a definitive list of entries for a given record. Once this list is compiled, blank records will be replaced with entries stating that the record was incomplete. Irrelevant entries will be removed from the report.

CREDO-I Event Summary and Search

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Number of Rows Retrieved: 1306

Site - Unit	Reactor or Test Unit	Event Date and Time	Occurrence Title & Report	System	SubSystem	Component	CID_Number
ANL - EBR-II	Reactor	2/15/1978 12:00 AM Details	[redacted]	AUXILIARY LIQUID NAK SYSTEM	PRIMARY COLD TRAP NAK COOLING SYSTEM	HEAT EXCHANGERS	[redacted]
ANL - EBR-II	Reactor	4/24/1991 8:00 AM Details	[redacted]	AUXILIARY LIQUID SODIUM INSTRUMENTATION SYSTEM	SECONDARY SODIUM STORAGE AND PROCESSING INST. SYSTEM	INDICATORS	[redacted]

Parameters

Select one or more Site - Units

ANL - EBR-II, ETEC - GPL-1A, E

Select System(s)

AC GENERATION AND DISTRIBI

Select Subsystem(s)

ARGON COOLING SYSTEM, ARC

Select Component(s)

BUS, CRDM, DETECTOR, EHEAT

Figure 28: Screen-shot of the CREDO-I summary event reports page.
Some content is redacted to protect the trade value of the database.

CREDO-I Event Detail

1. REPORT IDENTIFICATION

CREDO Report ID	Site	Unit	Reactor or Test Unit	Report Date	Occurrence Title	Occurrence Report	Version	Previous Report Date	Related Report	Event Date and Time
[redacted]	ANL	EBR-II	Reactor	[redacted]	Heat exchanger failure due to personnel error	[redacted]				

2. EVENT NARRATIVE

Event Narrative
[redacted]

3. EVENT DETECTION / IMMEDIATE ACTION

Detection Date and Time	Method of Detection	Time to Initial Action	Operating Status Unit	Operating Status System	Operating Status Subsystem	Initial Action
[redacted]						

4. COMPONENT FAILURE DATA

Component	Component Description	CREDO ID No	Site ID No	System	Subsystem	Event Cause	Event Cause Narrative
[redacted]				AUXILIARY LIQUID NAK SYSTEM	PRIMARY COLD TRAP NAK COOLING SYSTEM	OTHER	Because a maintenance personnel contacted helical tube with a drill bit.

Event Type	Event Mode	Event Severity	Primary or Secondary	Critical Parts	Event Effects system	number of hours lost	Event Effects unit	number of hours lost	Event Effects other
MECHANICAL	BREACH/RUPTURE	COMPLETE	[redacted]						

5. CORRECTIVE ACTION

Maintenance Action	Administrative Action	Interim Action	Final Action
[redacted]			Repaired breached tube

Figure 29: Screen-shot of the first five records in the CREDO-I detailed event reports page.
Some content is redacted to protect the trade value of the database.

5. CORRECTIVE ACTION

Maintenance Action	Administrative Action	Interim Action	Final Action
INPREP	NONE	N/A	Repaired breached tube

6. HUMAN INTERACTION DATA

Human Initiator (Y/N) : Explanation	Human Interaction OR Engineering Potential (Y/N): Explanation
YES: Maintenance man contacted helical tube with drill bit.	N/A

7a. MAINTENANCE DATA - GENERAL INFORMATION

Time Since Last Maintenance	Time Since Last Testing	Maintenance Narrative
[redacted]		

7b. MAINTENANCE DATA - RESTORATION TIME (Hours)

Total	Total Man	Administrative	Aministrative Man	Logistics	Indirect Repair	Indirect Man	Direct Repair	Direct Repair Man	Checkout/Retest	Checkout/Retest Man	Restart	Restart Man
[redacted]												

8. REMARKS

Comments or Discussion
N/A

9. SIGNATURES

Writer or Registrant
HUDSON, S.D.

10. COMPONENT ENGINEERING DATA

Date Installed	Date Removed	Details
1961-08-31		View Engineering Data Details

11. OPERATING DATA

Reporting Start Date	Reporting End Date	Details
1978-01-01	1978-03-31	View Operating Data Details

Figure 30: Screen-shot of the last six records in the CREDO-I detailed event reports page.
Some content is redacted to protect the trade value of the database.

The categories included in the detailed reports page are:

1. Report Identification This record includes the *CREDO Report ID*, the *Site* and *Unit* identification, *Report Date*, *Occurrence Title*, links to associated documentation, and revision history.

2. Event Narrative This record provides a free form field description of the event.

3. Event Detection and Immediate Action This record includes the time and date of the event, how the event was detected, the state of the unit, system, and subsystem when the event occurred, and any initial actions taken in response to the event.

4. Component Failure Data This record provides the system/subsystem/component and CREDO identification number mapping of the component in question, event cause/type/mode/severity categories and free form descriptions, and information regarding the subsequent impact of the event to the system and the unit.

5. Corrective Action This record provides categories for *Maintenance Action* and *Administrative Action* and free form records describing initial and final responses to the event.

6. Human Interaction Data This record provides a yes/no categorization to denote if the event was initiated by human action and a free form field to provide additional context.

7. Maintenance Data - a. General Information and b. Restoration Time This record summarizes the time in man-hours and calendar-hours that it took to restore the component. These records are recommended to be used with caution at this time due to noticed inconsistencies in the numbers reported and/or the utilization of the *Administrative*, *Logistics*, *Repair*, *Indirect Time*, *Checkout/Retest*, and *Restart* entries for many records. See Section 3.4 for more information.

8. Remarks This record provides an opportunity to capture additional information about the event of interest that was not otherwise captured in the detailed event data record.

9. Signatures This record provides a log of the individuals who modified the entries in this report. When SNL's development team notices an error in the CREDO-I entries, the SNL developer who updates the CREDO-I entry is appended here.

10. Component Engineering Data This new field provides a link to the associated component report (see Section 5.2.1.2).

11. Operating Data This new field provides a link to the associated unit operating report for the event (see Section 5.2.1.1). From the operating report the user can examine additional component failure events that occurred during the same reporting period.

5.2.2 CREDO-II Reports

The CREDO-II reports are found under the reports tab as shown in Figure 23. The CREDO-II database was created between 2013 and 2014 and was sourced with run logs from EBR-II, although the structure was generalized and source documentation was compiled for expansions of CREDO-II into FFTF, Fermi-I, SRE, and HNPF. This expansion was delayed while resources shifted to CREDO-I but most of these reactors are not found in CREDO-I and thus there is value-added to finishing the initial rollout of CREDO-II. Because CREDO-II serves as a supplemental and validation data source for CREDO-I, it will not be discussed in the same level of detail. The two CREDO-II reports are:

- Section 5.2.2.1 presents the event records for CREDO-II facilities.
- Section 5.2.2.2 presents the system diagram for CREDO-II facilities.
- Section 5.2.2.3 presents the document to event record mapping for CREDO-II facilities.

5.2.2.1 CREDO-II Event Report

The event reports store the failure event records for every unit included in the CREDO-II database. The CREDO-II event records were derived from a nearly complete set of run logs collected by SNL for EBR-II. The intent of this report was to consolidate all of the relevant event information preservable from run logs or unusual occurrence reports and consolidate the information into a database that could be used for reliability calculations with an emphasis on information traceability. Figure 31 shows that the event report includes: *Event ID*, *Event Description*, *Start & End Date*[10], *Component Name*, a link to the *System Diagram*, corrective *Action* classification, reactor *Power Level*, and yes/no classifications denoting if the event caused a *SCRAM*, *shutdown*, or *system outage*. The report can be sorted and/or filtered on the following records: *event description*, *document*, *power level*, and whether the event caused a system outage.

[10]To the degree retrievable from the source documentation (see Section 5.2.3).

Sodium Fast Reactor (SFR) Event Detail

Event ID	Event Description	Start & End Date		Component	Action	Document/Page	System Diagram	Power Level	Caused Scram?	Caused Shutdown?	System Out?
10001	[redacted]	1963-04-23	1963-??-??	Mechanical pumps	Repair	[redacted]	1.1	[redacted]	No	No	No
10002	[redacted]	1963-08-18	1964-??-??	Mechanical pumps	Repair	[redacted]	1.1	[redacted]	No	No	No
10003	[redacted]	1964-04-16	1964-??-??	Pipe and fittings	Repair	[redacted]	2.1	[redacted]	No	No	No
10004	[redacted]	1964-08-09	1964-08-09	Non-nuclear sensors	Repair	[redacted]	1.6.1	[redacted]	No	Yes	No
10005	[redacted]	1964-08-17	1964-08-17	Pipe and fittings	Repair	[redacted]	3.5	[redacted]	No	No	No
10006	[redacted]	1964-08-24	1964-09-23	N/A	Replace	[redacted]	4.10.2	[redacted]	No	No	No
10007	[redacted]	1964-08-17	1964-09-03	Pipe and fittings	Repair	[redacted]	3.5	[redacted]	No	No	No
10008	[redacted]	1964-10-02	1964-10-07	Valves	No Data	[redacted]	3.9	[redacted]	No	No	No
10009	[redacted]	1964-10-07	1964-10-09	Pipe and fittings	Repair	[redacted]	3.5	[redacted]	No	Yes	No
10010	[redacted]	1964-10-19	1964-10-19	Relays	No Data	[redacted]	7.1	[redacted]	Yes	No	No

Parameters

reactor name: EBR-II

Begin Start Year: 1963

End Start Year: 1994

component: ALL

action name: ALL

Caused Scram: ALL

Caused Shutdown: ALL

Figure 31: Screen-shot of the CREDO-II summary events reports page.
Some content is redacted to protect the trade value of the database.

5.2.2.2 CREDO-II System Diagram

The system diagram reports provide a basic *System/Subsystem/Component* relationship to the failure events described in the previous section. Because the run logs were not written to provide detailed maintenance accounting of the system, it was not always possible to identify events down to the component level. As seen in Figure 32 event records were traced to the lowest system, subsystem, or component identifiable.

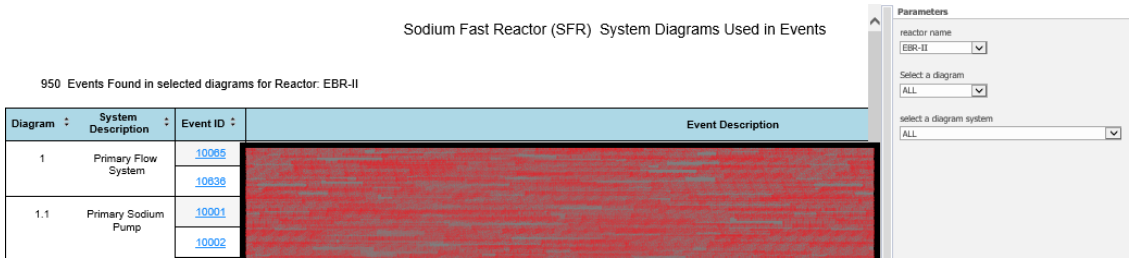

Figure 32: Screen-shot of the CREDO-II summary system diagram reports page.
Some content is redacted to protect the trade value of the database.

5.2.2.3 CREDO-II Document to Event Record Mapping

The document to event record mapping reports identifies every event listed in a run log or unusual occurrence report that has been incorporated into the CREDO-II database. The intent of this report, seen in Figure 33, was to provide traceability to the CREDO-II database. All referenced documents in the CREDO-II database can be found in the Supporting Documents tab of the SRD website as described in Section 5.2.3.

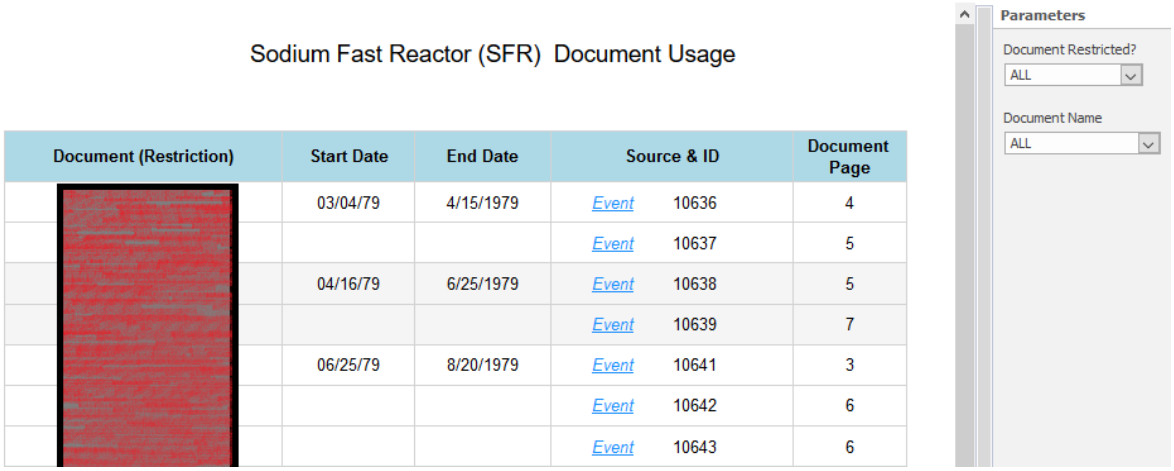

Figure 33: Screen-shot of the CREDO-II summary operating reports page.
Some content is redacted to protect the trade value of the database.

5.2.3 Supporting Documents

Because reliability data is in its basic form a simple structured record of operating data across facilities[11], document traceability is important to provide both confidence in the reported data and context for the information reported in the database. The importance of document traceability is increased due to the lack of initial CREDO data input forms. Documents which are relevant to providing an understanding of the SRDs are stored on the SRD website under the documents tab and are linked to the applicable reports in the CREDO-I and CREDO-II databases where possible.

The documents page shown in Figure 34 has three columns: Documents, Export Controlled, and Applied Technology. The Documents column contains information that either is marked unlimited release, is indicated by Office of Scientific and Technical Information (OSTI) to be unlimited release, or was secured by ANL from The Henry Ford Museum [27]. The Export Controlled column contains reports that have been mark as export controlled. The AT column contains legacy reports that have either been marked as AT or have not been cleared for release by the originating institution or OSTI[12]. Access to each column can be controlled by the SNL administrator at the discretion of the appropriate DOE program manager; see Section 5.1 for more information. Within each record the reports are broken down further by reactor and by the type of information contained within the document.

5.2.4 System Structure and Component Images

SRD records can be augmented with images and P&IDs to provide a more complete context to the end user of the SRD data. Figures that can be referenced by the SRDs are stored in a database found under the Images tab on the SRD website as shown in Figure 35. Images can be sorted by Image ID Number, Facility Name, and Report Number.

5.2.5 NaSCoRD Record Input Forms - Future Feature

Future SFR development will be supported by sodium experimental loops. In fact, important government funded experimental loops are already either operational or nearly operational at ANL [28] and the University of Wisconsin-Madison [29]. These loops and others that either already exist or will be built in the near future may benefit from the ETEC and WARD test loop information and would provide a unique source of information into the database which would benefit the entire sodium industry. To this end SNL is developing a capability to use forms within the SRD website to allow facility personnel to contribute to the NaSCoRD database.

Fortunately, the original input forms for CREDO were published [8]. These forms combine with the original CREDO user manual [25] to provide SNL developers with a first approxima-

[11] The database was structured to support multiple facilities but currently only includes EBR-II.

[12] As per DOE guidance given that the documents have not been approved for release by their originating facilities or OSTI.

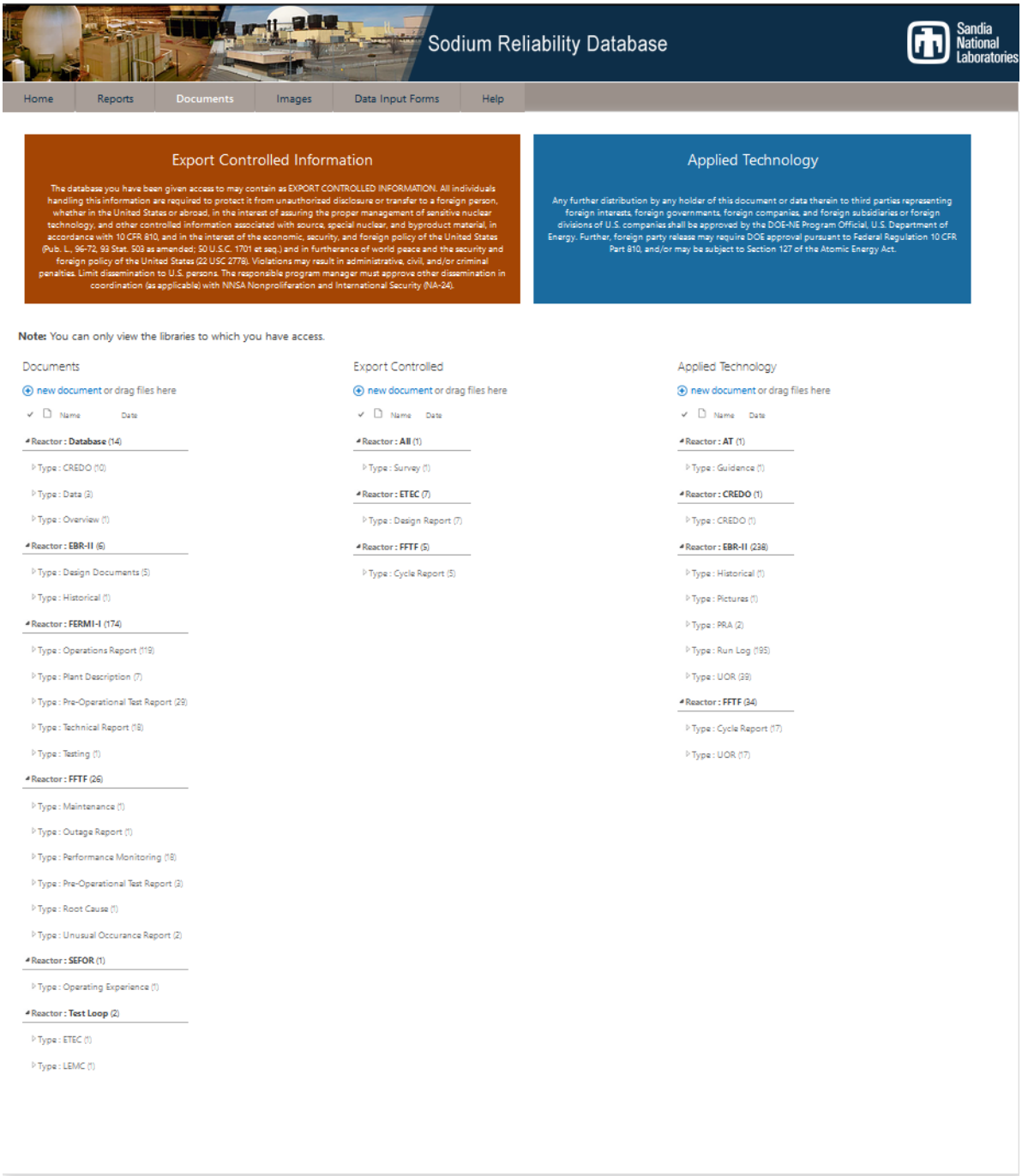

Figure 34: Screen-shot of the SRD supporting documents page.
The documents are divided by access level, then by reactor, and then by document type.

tion of what the NaSCoRD input forms should include. Beta-test facilities would likely iterate with NaSCoRD developers to ensure that the proper information is incorporated into the database. These forms will be accessed controlled so that only SNL developers and the form submitter would be able to access the forms before the data is integrated into NaSCoRD. Other users would see the new NaSCoRD records once they are integrated into the database. Supporting documents and

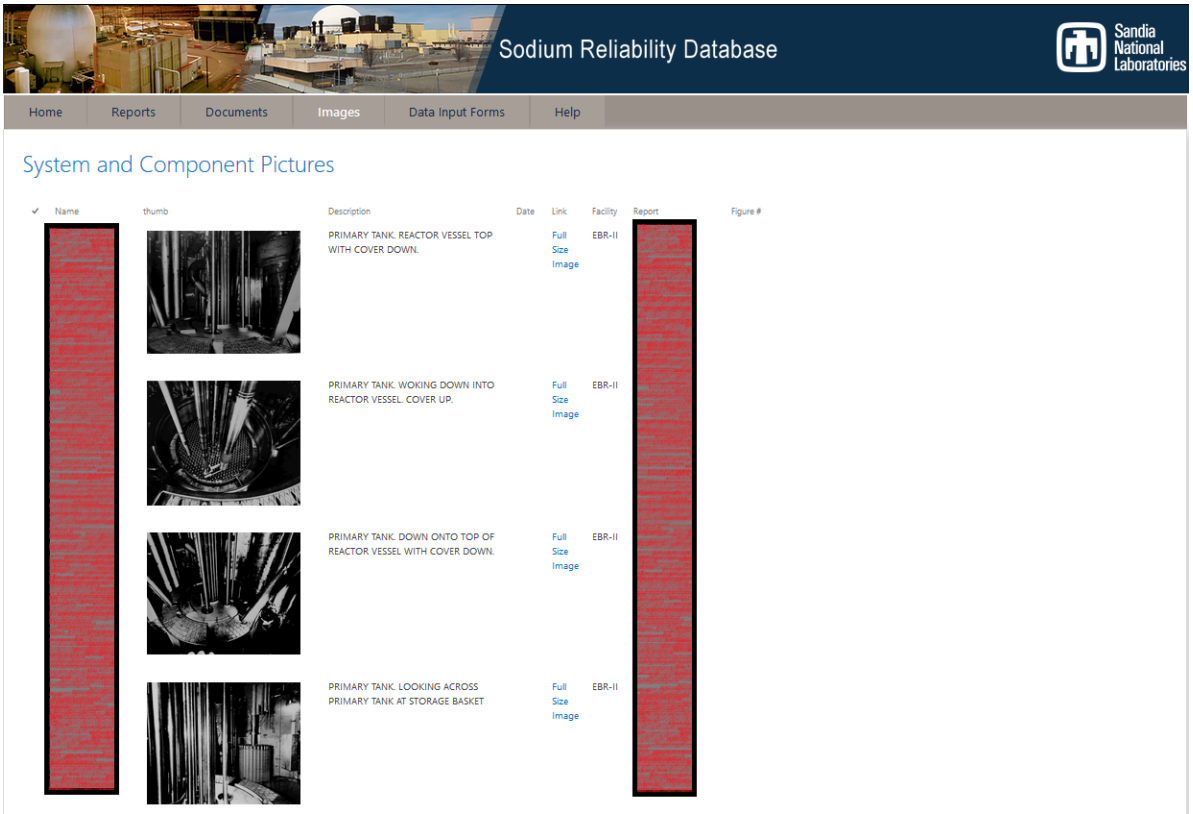

Figure 35: Screen-shot of the SRD Image database page.

images can be uploaded to the SRD forms and additional access controls can be established to further protect proprietary information if needed. Additional document categories with associated access controls can be added as necessary to the Documents tab (see Section 5.2.3). Example input forms can be seen in Appendix B.

5.2.6 System and Component Summaries - Future Feature

As the SRDs mature system and component summaries can help provide greater understanding and context to the data contained within the databases. The Reactor Operational Experience Results and Databases website [30] provides an overview of Light Water Reactor (LWR) system and component reliability studies. A high-level component summary without reliability data can be found in Appendix A.

5.3 Differences Between Internal vs External User Access

SNL SRD users have access to the SQL databases and can run direct SQL queries on the data, thus bypassing the SRD website reports. External users must go through the SRD website reports to pull data from the SQL databases. By providing search criteria to SNL staff, external users can

request new reports be generated with content specific to their needs. Data access controls are governed by the approval process discussed in Section 5.1. SNL policy does not allow outside users to directly access any SQL database.

5.4 Future of the Sodium Reliability Database Website

Future work on the SRD website, if authorized, will focus on the following areas:

Refinement of Conditional Records within the CREDO-I reports As highlighted from the large variation in field definitions and usage in the engineering component descriptions defined in Table 10, additional work should occur to adjust the records within the various reports based upon the context of the information being displayed. Currently all records are displayed in the report, whether the context allows for that field to be populated or not.

Creation of the NaSCoRD Input Forms As discussed in Section 5.2.5 the NaSCoRD input forms will initially be based upon the CREDO input forms to ensure maximum consistency with the existing data. SNL will iterate with external users to ensure that all necessary information for their facilities is adequately captured within the NaSCoRD database and forms. These forms will attempt to be as rich in feature context and supporting documents as possible. The CREDO-I effort has demonstrated how difficult it can be to fill in missing information in the future.

Preservation of Documents and Images and Subsequent Linking Many documents referenced in the CREDO-I reports have not yet been identified and uploaded to the SRD website. As documents and images are identified that would be useful to the end user, they will be uploaded and linked to the appropriate records.

Creation of the NaSCoRD Reports Once the new NaSCoRD SQL database is constructed, a report format will need to be developed to allow external users to benefit from the new features and data that will be available.

6 Conclusion

This report was written as part of a DOE:NE ART program funded project, AT-17SN170208 SFR Database Development (CREDO) - SNL, to re-create the capabilities of the legacy CREDO database [1, 2]. The US-facility-only version of the CREDO database, referred to in this report as CREDO-I, was retrieved from JAEA in August of 2016. SNL's efforts in 2017 have mainly focused on migrating the this data into a Microsoft-SQL database, decoding the data, and producing reports on a restricted access SRD website to allow the SFR community to access reports created from the database. This database preserves and organizes key operational insights from FFTF, EBR-II, and multiple test loops that were operated throughout the nuclear energy complex.

6.1 Primary Insights

After analyzing the CREDO-I data for nearly a year the following conclusions can be reached:

- Inconsistencies in the CREDO-I data make it difficult to use this information as-is to derive failure probabilities for PRA applications.
  - Resolution of the majority of entry inconsistencies within CREDO will require a continued effort to identify, process, and extract corroborative information from operational logs, maintenance records, and unusual occurrence reports.
  - Processes need to be established to explore the impact of entry inconsistencies that cannot be reconciled.
- CREDO-I, CREDO-II, and NaSCoRD data will have immediate benefits to sodium system designers who can extract engineering, operational, and safety insights from these data sets. The ability to examine the failure modes for sodium components and examine which environments led to multiple and repeated component failures will allow for future sodium loop and sodium reactor designers to leverage the expansive legacy of sodium reactor operations.
- The expansion of NaSCoRD to incorporate new sources of facility data will provide the US with the best opportunity to develop a true database to support future PRA applications.

6.2 Summary of Report Contents

Section 2 summarizes the contents of the CREDO-I database, including time histories and histograms of operational, engineering, and failure event data, and outlines future methods for extracting reliability information from this data.

Section 3 describes the QA efforts that have been conducted to ensure that the CREDO-I data as consistent and error free as possible. Without the original CREDO input forms for recorded events

SNL has used multiple consistency checks to identify and correct multiple errors in the CREDO-I data. Previous efforts to create the CREDO-II database from source documents were demonstrated to be invaluable in the overall CREDO-I QA process.

Section 4 presents a new SRD, referred to as NaSCoRD, which is the product of combining CREDO-I records with both CREDO-II and new facility information. This SRD will expand with the new SFR community and support their ever-growing research and safety assessment needs.

Section 5 describes the restricted web interface for CREDO-I and CREDO-II. The CREDO-I SQL reports lay out Engineering, Operational, and Event data in a two layer format. The first layer is intended to allow the user to quickly sort and filter records. The second layer of the report provides detailed information about each record, including relationships to other types of reports. For example, the detailed engineering report on a specific component will link to all failure events that were recorded associated with that component. Additional reports and sorting/filtering options can be added to the SRD website as external users request new features. The content of each report is described to assist new users in locating information relevant to their needs.

References

[1] T. Bott, G. Cunningham, N. Greene, P. Haas, S. Hudson, H. Knee, and J. Manning, "Development of the Centralized Reliability Data Organization (CREDO)," Oak Ridge National Laboratory, Oak Ridge, TN, CONF-800459–1, 1980.

[2] P. Haas, T. Bott, H. Knee, J. Manning, S. Hudson, N. Greene, and M. Woodside, "Development of the Centralized Reliability Data Organization (CREDO)," Oak Ridge National Laboratory, Oak Ridge, TN, CONF-791103–99, 1979.

[3] M. Denman, J. LaChance, T. Sofu, G. Flanagan, R. Wigeland, and R. Bari, "Sodium Fast Reactor Safety and Licensing Research Plan Volume I," Sandia National Laboratories, SAND2012-4260, May 2012.

[4] "Email from Christopher Grandy," August 11, 2016.

[5] "Failure Data Handbook for Nuclear Power Facilities - Volume I Failure Data and Applications Technology," Liquid Metal Engineering Center, Canoga Park, CA, LMEC-Memo-69-7 Volume I, Revision 1, June 1970.

[6] "Failure Data Handbook for Nuclear Power Facilities - Volume II Failure Category Identification and Glossary," Liquid Metal Engineering Center, Canoga Park, CA, LMEC-Memo-69-7 Volume II, June 1969.

[7] "Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," United States Nuclear Regulatory Commission, Washington, DC, WASH-1400 (NUREG 75-014), October 1975.

[8] H. Knee, "The Centralized Reliability Data Organization (CREDO); an Advanced Nuclear Reactor Reliability, Availability, and Maintainability Data Bank and Data Analysis Center," in *Reliability Data Banks*, A. Cannon and A. Bendell, Eds. London: Elsevier Applied Science, 1991, ch. 7, pp. 101–144.

[9] "Clinch River Breeder Reactor Plant Probabilistic Risk Assessment Volume 3," Technology for Energy Corporation, Knoxville, TN, CRBRP-4, USNRC ML081430289, 1984.

[10] "PRISM Preliminary Safety Information Document," General Electric, San Jose, California, GEFR-00793, 1987.

[11] M. Smith and W. Ragland, "Interaction of CREDO with the EBR-II PRA Development," in *Transactions of the American Nuclear Society*, vol. 60. San Francisco, CA: American Nuclear Society, Nov 1989, pp. 411–412.

[12] D. Hill, Y. Chang, L. Deitrich, W. Lehto, W. Ragland, and R. Schaeffer, "An Overview of the EBR-II PRA," Argonne National Laboratory, Argonne, IL, CONF-900804–17, 1990.

[13] M. Smith and J. Manneschmidt, "Report of Foreign Travel of M.S. Smith and J.F. Manneschmidt," Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/FTR–3864, 1991.

[14] "Conversation with George Flanagan," 2014.

[15] T. Bott and P. Haas, "Analysis of Sodium Valve Reliability Data at CREDO," Oak Ridge National Laboratory, Oak Ridge, TN, CONF-790816–19, 1979.

[16] S. Painter, H. Knee, and B. Humphrys, "CREDO Analysis: A Comparison of Liquid Metal and Water Valve Reliabilities," Oak Ridge National Laboratory, Oak Ridge, TN, CONF-850713–4, 1985.

[17] D. Wood, M. Smith, and J. Drischler, "Motor-Operated Globe Valve Performance in a Liquid Sodium Environment," Oak Ridge National Laboratory, Oak Ridge, TN, CONF-920818–2, 1992.

[18] L. Cadwallader, "Reliability and Maintainability Data for Liquid Metal Cooling Systems," in *2015 IEEE 26th Symposium on Fusion Engineering (SOFE)*, May 2015.

[19] P. Ramuhalli, R. Hirt, A. Veeramany, C. Bonebrake, B. I. Jr, G. Coles, J. Coble, X. Liu, D. Wootan, M. Mitchell, and M. Brass, "Prototypic Enhanced Risk Monitor Framework and Evaluation," Pacific Northwest National Laboratory, Richland, WA, PNNL-24712 Revision 0, September 2015.

[20] D. Grabaskas, A. J. Brunett, and M. Bucknor, "A Methodology for the Development of a Reliability Database for an Advanced Reactor Probabilistic Risk Assessment," in *Proceedings of the 24th International Conference on Nuclear Engineering*. Charlotte, NC: American Society of Mechanical Engineers, June 2016.

[21] S. A. Eide, S. V. Chmielewski, and T. D. Swantz, "Generic, Component Failure Data Base for Light Water and Liquid Sodium Reactor PRAs," Idaho Engineering National Laboratory, Idaho Falls, ID, EGG-SSRE-8875, February 1990.

[22] J. Poloski, C. Grant, C. Gentillon, and W. Roesener, "Reliability Study: Reactor Core Isolation Cooling System, 1987-1993," U.S. Nuclear Regulatory Commission, NUREG-CR-5500, INEL-95/0196, 1999.

[23] R. Cooke and T. Bedford, "Analysis of reliability data using subsurvival functions and censoring models," in *Recent Advances in Life-Testing and Reliability*. Boca Raton, FL: CRC Press, 1995.

[24] "Sql server machine learning services," https://docs.microsoft.com/en-us/sql/advanced-analytics/r/sql-server-r-services, accessed: 2017-08-26.

[25] J. Manning, H. Knee, P. Seagle, M. Allen, M. Anderson, B. Humphrys, and S. Painter, "A Guide for Completing Input Data Forms for CREDO - A Centralized Reliability, Availability, and Maintainability Analysis Center for Liquid-Metal-Cooled Reactor and Test Facility Components," Oak Ridge National Laboratory, Oak Ridge, TN, ORNL/TM-9892. Limited Distribution, 1986.

[26] D. Wootan, R. Omberg, T. Sofu, and C. Grandy, "Passive Safety Testing at the Fast Flux Test Facility Relevant to New LMR Designs," in *International Conference on Fast Reactor and Related Fuel Cycles*, Yekaterinburg, Russia, June 2017.

[27] "Finding Aid for Enrico Fermi Atomic Power Plant Records, 1952-1975," The Henry Ford, Dearborn, MI, Accession 75.2, January 2011.

[28] M. Hvasta, C. Grandy, D. Lisowski, and A. Borowski, "Mechanisms Engineering Test Loop Phase I Status Report FY2015," Argonne National Laboratory, Argonne, IL, ANL-ART-24, September 2015.

[29] M. Anderson, "Component and Technology Development for Advanced Liquid Metal Reactors," Department of Energy Nuclear Energy University Programs, Madison, WI, Project No. 13-4955, January 2017.

[30] J. C. Lane, "NRC Operating Experience (OpE) Programs," U.S. Nuclear Regulatory Commission, ML091320447, July 2015.

[31] K. Koger, M. Haire, B. Humphrys, J. Manneschmidt, K. Setoguchi, and R. Nakai, "The Centralized Reliability Data Organization (CREDO) Assessment of Critical Component Unavailability in Liquid Metal Reactors," Oak Ridge National Laboratory, Oak Ridge, TN, CONF-880601–34, 1988.

A Example System Summary: Control Rod Drive Mechanism

This appendix contains results of an initial data analysis of the CRDMs from CREDO-I. A previous data analysis of critical components [31] conducted when the CREDO database was active in the US did not provide direct reliability estimates of CRDMs. Generic numbers around 10^{-5} to 10^{-6} per demand have typically been used.

Figures A.1 and A.2 show the time history trend in CRDM failures for EBR-II and FFTF. Failures of CRDMs was an expected occurrence across both reactors. These failures did not typically result in significant downtime for the facility. EBR-II lost more system time due to CRDM failures than FFTF. Of note:

- 1984 recorded 3.8 days of integrated system unavailability in EBR-II.
- 1985 recorded 6.7 days of integrated system unavailability in EBR-II.
- 1986 recorded 3.4 days of integrated system unavailability in EBR-II.
- 1987 recorded 29.1 days of integrated system unavailability in EBR-II.
- 1988 recorded 0.0 days of integrated system unavailability in EBR-II.
- 1989 recorded 2.9 days of integrated system unavailability in EBR-II.

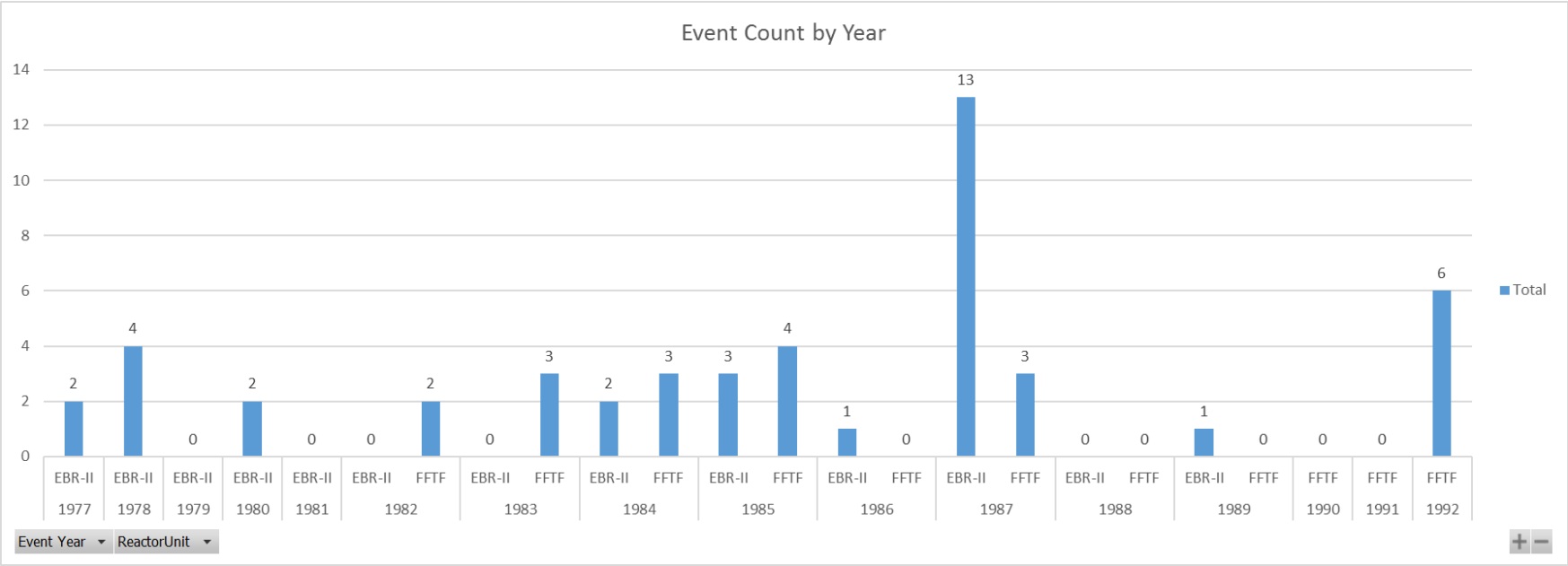

Figure A.1: CREDO Recorded CRDM events for FFTF and EBR-II between 1977 and 1992.

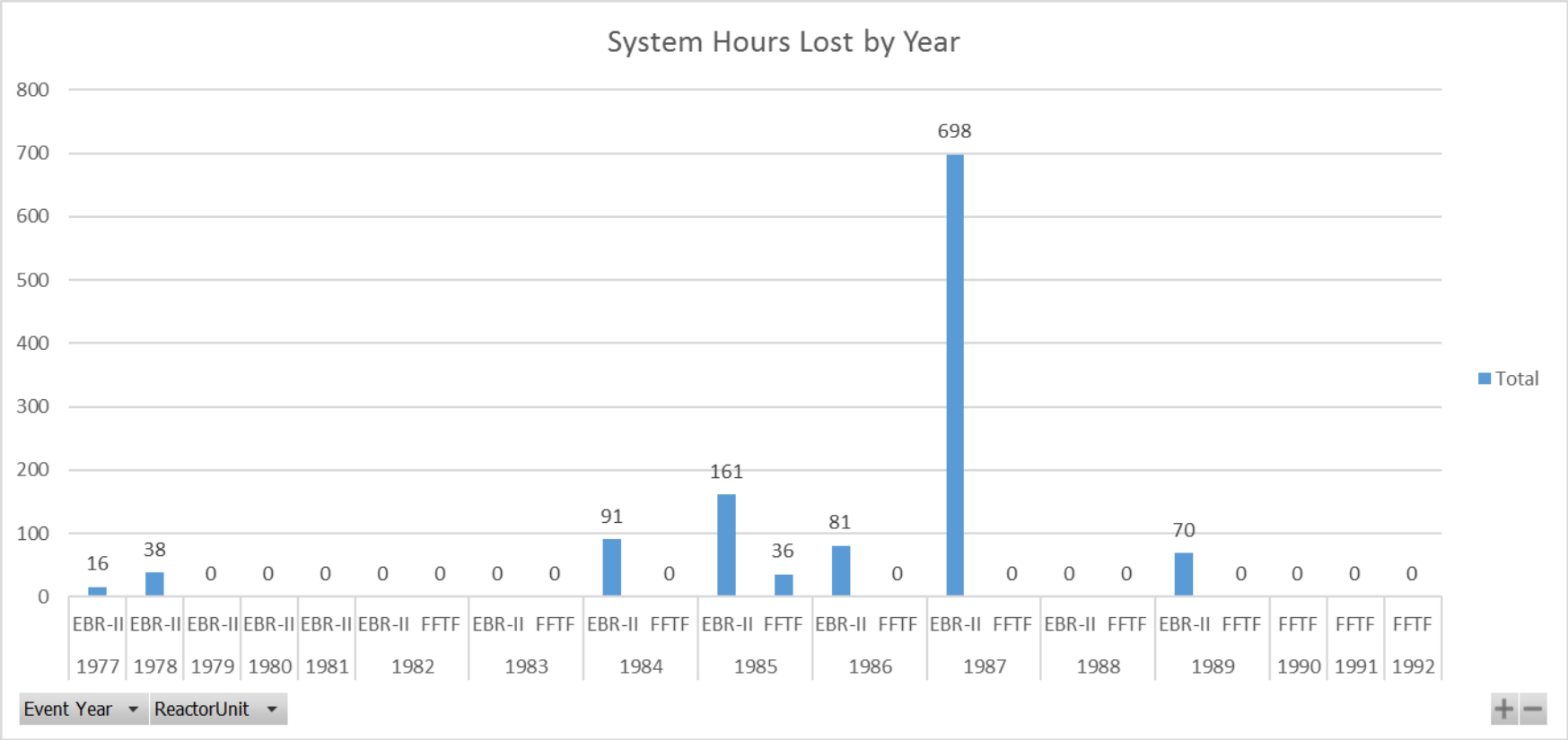

Figure A.2: CREDO Recorded System Hours Lost for FFTF and EBR-II between 1977 and 1992.

From Figures A.1 and A.2, the CRDM failures experienced at EBR-II in 1987 dominated the total number of failures and the corresponding restoration time. These 13 data points where segregated and examined separately. Most of these failures were caused by mechanical wear as shown in Figure A.3. All of these failures were experienced during shutdown maintenance and testing.

Figure A.3 divides the CRDM failure restoration time by type and mode. Mechanical failure took the longest to repair, with cracks and abnormal operations dominating the cumulative repair times. In general, electrical (power) and electronic (control system) issues were more easily repaired.

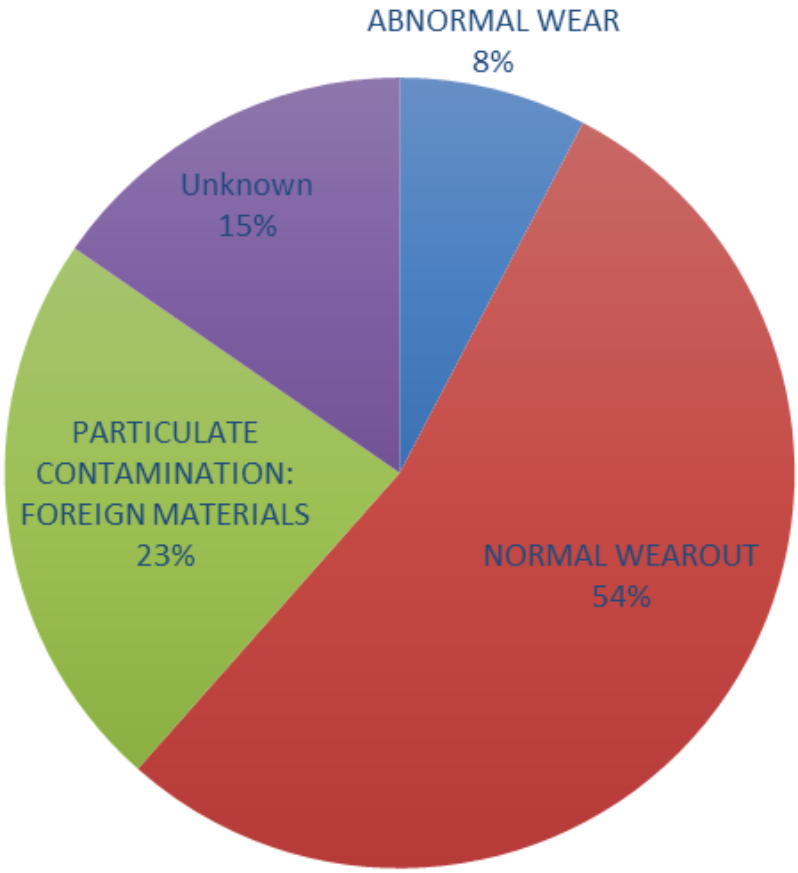

Figure A.3: CREDO Recorded EBR-II 1987 Outage CRDM Failure Causes, Thirteen Total Failures.

Figure A.4 compares the calendar time to the man hour repair time for FFTF and EBR-II. EBR-II often reported shorter calendar time than man-time; multiple failures were likely repaired simultaneously during outages. FFTF reported the same calendar time and man-time. In contrast to EBR-II, it appears that FFTF staff likely repaired the CRDMs serially as they failed.

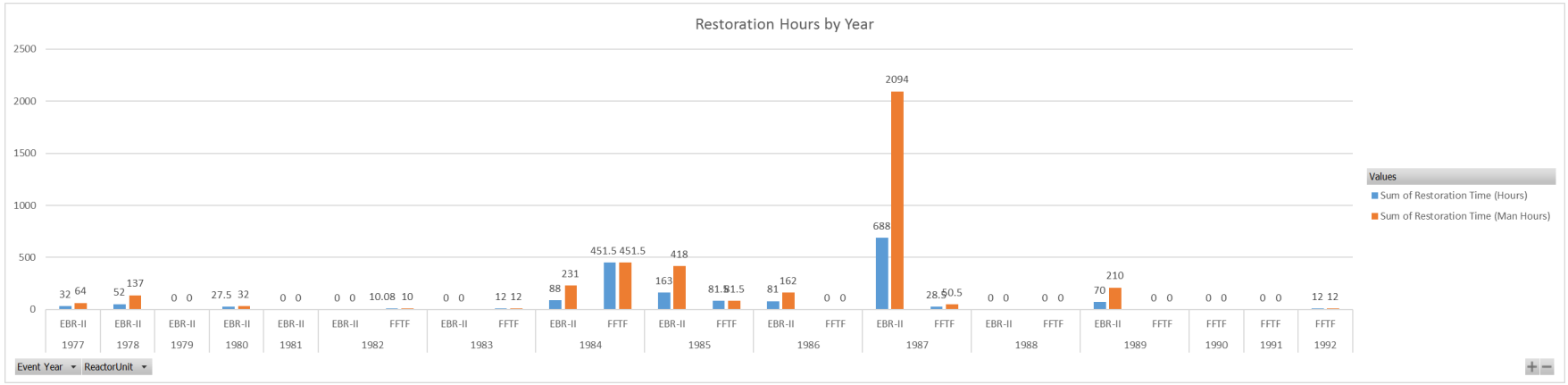

Figure A.4: CREDO Recorded CDRM Related Restoration Man Hours Divided by Failure Modes.

B Proposed NaSCoRD Input Forms

The ORNL CREDO development team created forms that user facilities completed to document the components, operational history, and failure events for the facility. The SNL development team will uses these forms as a starting point for iterations with future facility's staff. Appendix B outlines the following input forms that will be recreated on the SRD website:

- Section B.1 presents the engineering input forms which record each NaSCoRD related component used in the facility. A facility would fill out individual forms for all relevant components when a facility is added to the NaSCoRD database and then as components are either removed from or added to the facility.
- Section B.2 presents the facility operating input form which records the amount of time the facility spends in each operating mode in the previous reporting period, typically quarterly. Abnormal operating conditions that may impact failure rates, such as extended and abnormal preventative maintenance, would be recorded in this form.
- Section B.3 presents the facility event input form which records the component failure events experienced by the facility. A facility would fill out a form after every component failure event.

B.1 NaSCoRD Engineering Input Form

B.1.1 Report Identification

- Site:
- Unit:
- Report Date:
- Report Status (New/Change/Delete):
  - If Change or Delete, Previous Report Date:

B.1.2 Component Identification

- Name:
- Site I.D. Number:
- Facility Protection System (Y/N):
- Model Number:
- Manufacturer:
- Code:
- Specification/Standard:
- Safety/Quality Class(es):
- Drawing Number: Site: Manufacturer:
- Drawing File:
- Date Installed:
- Date Removed:
  - Failed (Y/N):
  - Censored (Y/N):
  - Extension (Y/N):
    - Design:
    - Usage:

B.1.3 Component Use and General Design Information

- System:
- Subsystem:
- Design Function:
- Application:
- Design Life (Y/N)(hours):
- Design Life (Y/N)(cycles):
- Design Requirements Document:

B.1.4 Operating Factors

Expected % of Time the Component Operates in Each Mode:

- Isothermal Operations:
- Shutting Down, Startup, Thermal-Hydraulic Transient Operations:
- Drained, Shutdown:

If Change:

- Upload Operating Factor History

B.1.5 Duty Factors

Expected Cycles per Hour the Component Operates in Each Mode:

- Isothermal Operations:
- Shutting Down, Startup, Thermal-Hydraulic Transient Operations:
- Drained, Shutdown:

If Change:

- Upload Duty Factor History

B.1.6 Maintenance and Inspection/Test Data

- Maintenance Interval (per year):
- Maintenance Type:
- Maintenance Report:
- Inspection Interval (per year):
- Inspection Type:
- Inspection Report:
  If Change:
  - Upload Maintenance History:
  - Upload Inspection History:

B.1.7 Radiation Environment

- Radiation Environment(Y/N):
- Neutron Flux Level (n/cm^2s):
- Gamma Flux Level ($photons/cm^2s$):

B.1.8 Redundant and/or Replicate Component

Select component from database:

B.1.9 Additional Information

Remarks:

B.1.10 Signatures

- Last Name, Initials:
- Email:
- Phone:

B.2 NaSCoRD Operational Input Form

B.2.1 Report Identification

- Site:
- Unit:
- Report Date:
- Report Period Dates:
  - Begin Date:
  - End Date:

B.2.2 Operating Times

Report Hours in Each Operational Mode:

- Isothermal Operations:
- Shutting Down, Startup, Thermal-Hydraulic Transient Operations:
- Drained, Shutdown:

B.2.3 Number of Events Reported This Period

Number of Events:

B.2.4 Facility Data

- Design Output (MWt):
- Authorized Output (MWt):
- Report Period Total Output ($MWt - hr$):
- Outages:
  - Scheduled:
    - Number:
    - Hours Expended:
  - Unscheduled:
    - Number:
    - Hours Expended:
- Comments:
- Number of Transient Cycles:
- Total Hours In Transient or Cyclic Conditions:

B.2.5 Signatures

- Last Name, Initials:
- Email:
- Phone:

B.3 NaSCoRD Event Input Form

B.3.1 Report Identification

- Site:
- Unit:
- Report Date:
- Occurrence Title:
- Report Status (New or Changed):
  - Previous Report Date:
- Related Reports:
  - Unusual Occurrence Report
    - Title:
    - File:
  - Other Report
    - Title:
    - File:
- Event Date:
- Event Calendar Time (hours):

B.3.2 Event Narrative

Narrative:

B.3.3 Event Detection and Immediate Action

- Detection Date:
- Detection Time:
- Method of Detection:
- Hours from Detection to Initial Action:
- Operating State:
  - Unit:
  - System:
- Initial Action:

B.3.4 Component Failure Data

- Component Name:
- Site I.D. Number:
- System:
- Subsystem:
- Component Description:
- Event Type:
- Event Mode:
- Event Cause:
- Event Severity:
- Primary Loop or Support Loop:
- Event Cause Narrative:
- Event Effects:
  - Subsystem Status and Hours Lost:
  - Unit Status and Hours Lost:
  - Other Systems Impacted and Hours Lost
- Critical Parts that Caused the Event:

B.3.5 Corrective Action

- Maintenance Action:
- Administrate Action:
- Interim:
- Final:

B.3.6 Human Interaction Data

Human Initiator (Y/N):

- If yes, explain:
- Human-Machine-Interface Insights:

B.3.7 Maintenance Data

Restoration Time (calendar and working hours):

- Total:
- Administrative:
- Logistics:
- Indirect Repair:
- Direct Repair:
- Checkout and Restart:
- Restart:

Time from last:

- Maintenance:
- Testing:

Maintenance Narrative:

B.3.8 Additional Information

Remarks:

B.3.9 Signatures

- Last Name, Initials:
- Email:
- Phone:

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