Development of the U.S. Sodium Component Reliability Database

Matthew Denman[1], Zachary Jankovsky[1], Andrew Cark[1]

[1]Sandia National Laboratories (SNL), Albuquerque, New Mexico

E-mail contact of main author: matthew.denman@sandia.gov

Abstract. With the advent of the use of Probabilistic Risk Assessments (PRAs) for safety analysis of Light Water Reactors (LWRs) in the 1970s, the sodium fast reactor (SFR) community used PRA as a tool which can demonstrate the safety of SFR designs while avoiding the pitfalls associated with an over-reliance on highly conservative safety requirements. Throughout the 1970s, 80s, and 90s, the US compiled sodium reactor specific PRA information into the Centralized Reliability Database Organization (CREDO) database, maintained by Oak Ridge National Laboratories in collaboration with the Japanese Atomic Energy Agency (JAEA). Unfortunately, the funding for the CREDO database was cut in the 1990s and the database was lost and was regained in August of 2016. This paper will describe three databases being developed at Sandia National Laboratories (SNL): 1. CREDO-I – A summary of the state of the original CREDO database; 2. CREDO-II – Early attempts by Argonne National Laboratory (ANL) and SNL to recreate the CREDO database from operational documents; 3. The future combination of the CREDO-I and CREDO-II databases into a unified database.

Key Words: CREDO; PRA; Reliability

1. Introduction

Both the United States (US) and the international community have a long history of designing, building and operating Sodium Fast Reactors (SFRs).[1] The safety requirements for the first SFRs were determined through the use of conservative safety margins to account for unknown–unknowns associated with a technology. This approach proved particularly challenging to SFRs because infeasible events, such as Hypothetical Core Disruptive Accidents (HCDAs), had to be accommodated by SFR designs. These accidents, often proposed without a mechanistic initiator, proved to be a driver of high SFR licensing costs and eventually contributed to the withdrawal of the Clinch River Breeder Reactor (CRBR) license application to the Nuclear Regulatory Commission (NRC).[2]

With the advent of the use of Probabilistic Risk Assessments (PRAs) for safety analysis of Light Water Reactors (LWRs) in the 1970s, the SFR community used PRA as a tool which can demonstrate the safety of SFR designs while avoiding the pitfalls associated with an overreliance on highly conservative safety requirements. PRAs are logical tools which combine accident initiators, logical arguments for system availability, and basic event probabilities to provide an estimate of the overall system reliability. Throughout the 1970s, 80s, and 90s, the US compiled sodium reactor specific PRA information into the Centralized Reliability Database Organization (CREDO) database, maintained by Oak Ridge National Laboratories [3-11] in collaboration with the Japanese Atomic Energy Agency (JAEA). Unfortunately, the funding for the CREDO database was cut in the 1990s and the database was lost to the United States government.[3] In August of 2016, the United States government received the United States facility data contained in the Japanese version of the CREDO database from JAEA. This paper documents:

- CREDO-I – The current state of the CREDO database which was received form JAEA in August 2016;

- CREDO-II – Early attempts by Argonne National Laboratory (ANL) and Sandia National Laboratories (SNL) to recreate the CREDO database;
- NaSCoRD – The future combination of CREDO-I and CREDO-II; and
- Accessibility – The current infrastructure and environment hosting the CREDO databases.

2. Reliability Databases

A United States SFR developed and maintained reliability database has not been supported since the early 1990s. At that point in time, mainframe computer space was limited and queries of large databases were resource intensive. Computer and cloud based infrastructure have improved dramatically since the 1900s; any new effort to develop a database today will naturally leverage the current state of the art in database technology. As a result, the emphasis of the current database work is threefold:

- **Make the database contents as easy to understand and search as possible.** Acronyms uses to save computational space in previous versions of CREDO are being removed to improve accessibility.
- **Make the database as feature rich as possible.** Links to supporting documents, figures, and diagrams will be employed to the fullest extent possible to allow future analysts to have access to all the available information about a given event or system without needing to perform additional research.
- **Allow for the easy extraction of reliability information.** Reliability databases are useful for many system engineering applications but still are intended to primarily provide basic event failure probabilities for PRA applications.

The following sections will describe the CREDO-I, CREDO-II, and NaSCoRD database. These databases are all intended to meet the three objectives listed above; although the databases in their current states accomplish these goals to various degrees. At the current time the goals of making the database easy to understand and feature rich are near term objectives, while providing reliability information is dependent on the development of proper relationship definitions for the database.

2.1.CREDO-I

CREDO-I was received from JAEA in August of 2016. A basic database structure was created from this data and is shown in its current state in FIG. 1. The CREDO-I database includes:

- 1306 event records (i.e., what, when, and why did something happened and what was done about it),
- 408 facility operating records (i.e., describing a given facility's operating state as function of time), and
- 8102 engineering data records (i.e. component descriptions)

Over the next year, SNL will establish the relationships between the Event, Operating, and Engineering data and consolidate this data with that collected in CREDO-II. One challenge in the use of the CREDO-I data is that the reports themselves are not available. In some cases there is ambiguity in the physical meaning of records, for example in the operating mode for facility operating records. In CREDO reports a coded term was used to refer to each numbered operating mode, such as "PWROPS" for power operations. This code was accompanied with a number of hours for that reporting period. The code is not included in the

CREDO-I data, so the meaning of each mode (numbered 1 to 3) for each reactor and test loop must be determined by other methods.

The already-gathered data in CREDO-II can be used to understand CREDO-I data. The annual critical reactor time (in hours) for EBR-II assembled from daily and run records in CREDO-II is compared to the annual time in each operating mode assembled from quarterly records from CREDO-I in FIG. 2. It can be seen that from the operating modes allowed in CREDO, such as cold shutdown, hot shutdown, refueling, power operations, etc., operating mode 1 most likely refers to power operations for EBR-II. There are years where the CREDO-II critical hours are significantly less than the CREDO-I operating mode 1 hours; these are cases of unavailable reactor operation logs, and demonstrate a situation where the two databases may complement each other in the creation of a unified database.

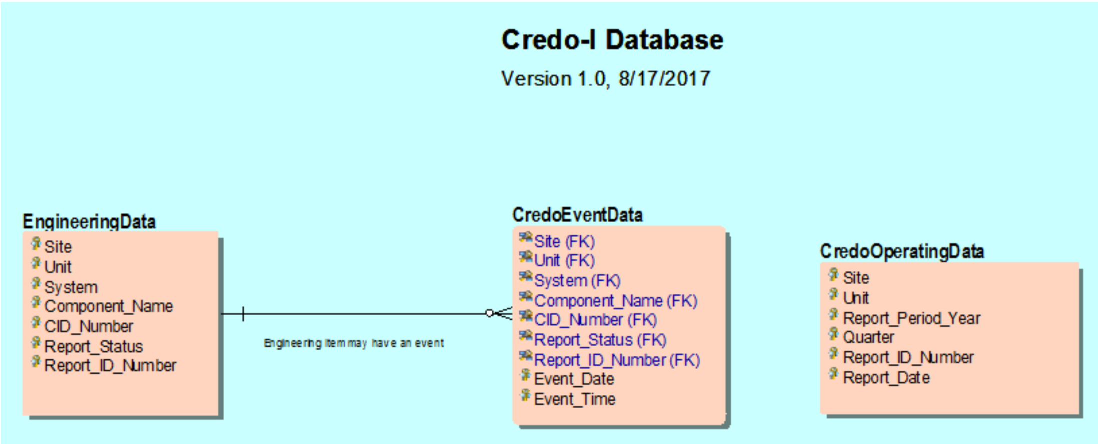

FIG. 1. CREDO-I Database Diagram.

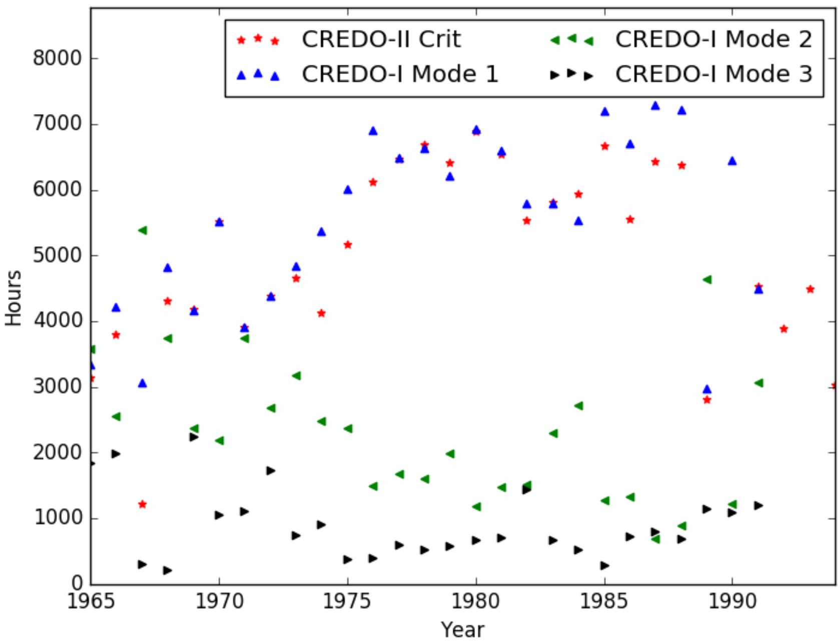

FIG. 2. CREDO Operating Mode Comparison for EBR-II.

By a similar method, the meaning of the CREDO-I field “Report Period Total Output” was determined for EBR-II. It was initially unclear what parameter this represented as well as what units were used. It was suspected to reflect either the electric or thermal output of the reactor, both of which were available in the CREDO-II operational history tables. The CREDO-I output and CREDO-II thermal and electric outputs are presented by year in FIG. 3.

For most years, the CREDO-I EBR-II output matches CREDO-II electric production closely. There are discrepancies, particularly large in the early 1980s, which will be examined further and may require adjustment of the data if a definitive source is identified.

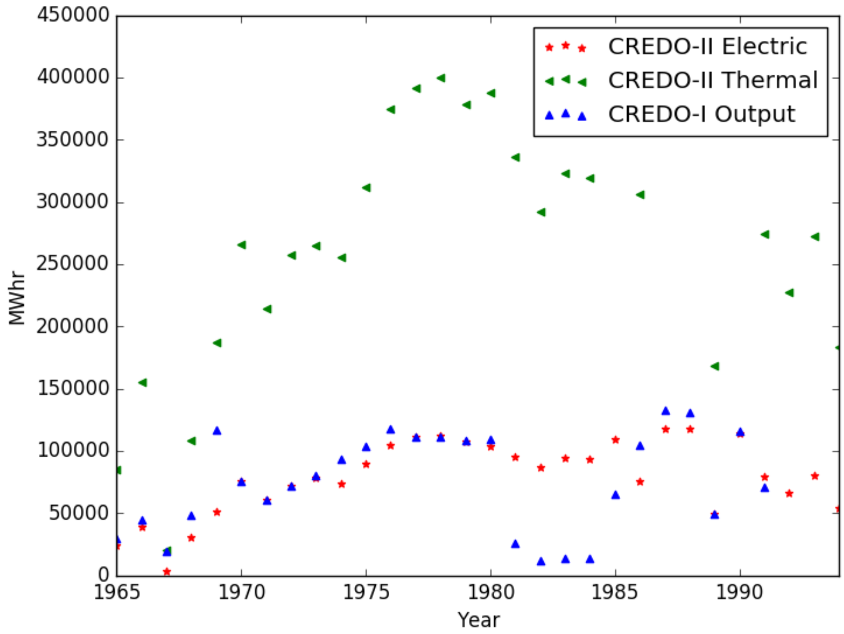

FIG. 3. CREDO Output Comparison for EBR-II.

2.2.CREDO-II

In 2013 an effort began to reclaim the reliability data that was lost with CREDO in the 1990s. This took a two-pronged approach, involving a search for extant copies of CREDO itself and an effort to recreate CREDO using historical documents. The retrieval of data from historical sources was aided by the existence of a book which contained copies of the data submittal forms used by CREDO.[11] These forms specified the engineering, operations, and event data that would be submitted to CREDO by member facilities. They were useful in guiding the gathering of operating and event data from reactor run logs and event reports. Engineering data are not a part of the CREDO-II database, as a limited amount is available in the open and proprietary documents collected thus far.

The primary challenge in attempting to recreate the database from historical records is that the available documents were not intended to fully describe reliability-significant events. The majority of the documents are run-based or time-based summaries of activity that were written as periodic project deliverables. In many cases the starting and resolution dates of events are not given. Specific item identifiers are rarely given; rather, a run log event narrative may simply refer to "a valve" within a specified sub-system. Strategies have been developed to deal with uncertainty in event occurrence and resolution dates.

The database and associated relationships are outlined in FIG. 4. Each event is associated with a document and page number, a specific reactor, a corrective action, and a specific sub-system of that reactor. Actions may include repair, replacement, addition to, or removal from the system. The operational data are separated into run-based and daily history entries. Because reactors differed in the frequency of operational reporting, the run history table is flexible and allows a start and end date to be set for each entry. This permits data to be recorded whether it was provided for each week, quarter, or time-variable reactor run.

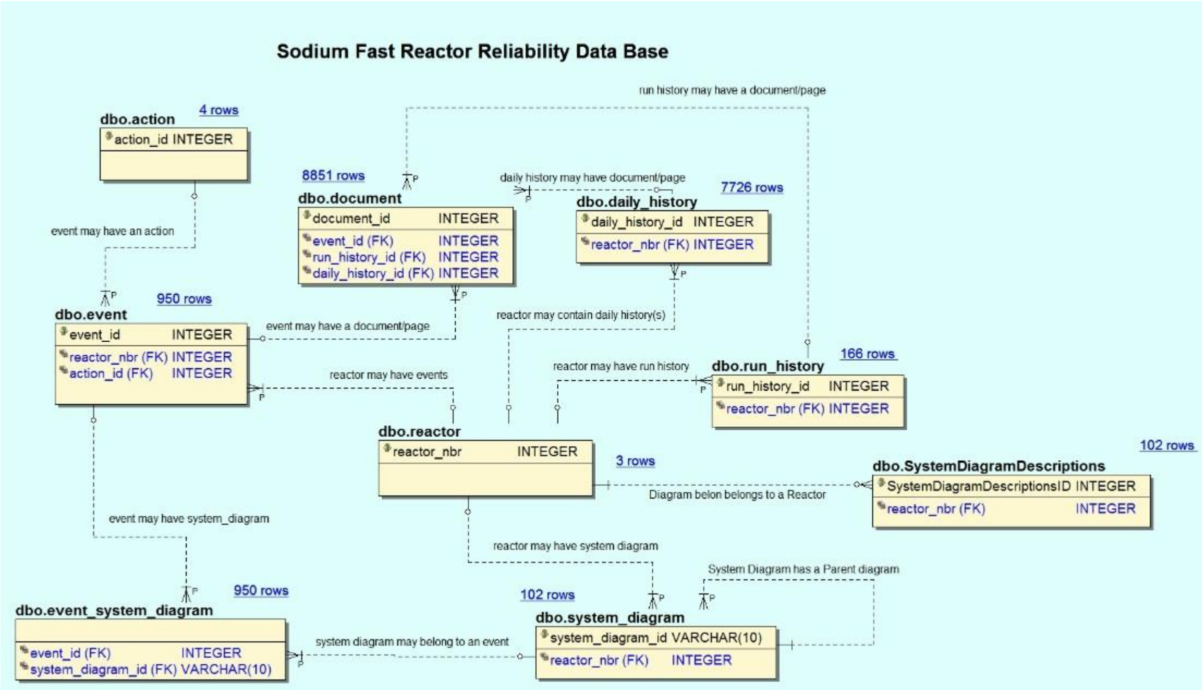

FIG. 4. CREDO-II Database Diagram.

A system hierarchy for each reactor has been assembled from documents and is used to sort the sub-systems affected by each event. For example, an event may be assigned to the primary coolant system (1), the primary coolant pump (1.1), the primary coolant pump motor (1.1.1), or the primary coolant pump motor clutch (1.1.1.1). The event is assigned as specifically as possible given the narrative and its context in a report.

Even with the acquisition of CREDO-I, CREDO-II is not being abandoned due to the document tractability aspect of this database. Sandia has collected and indexed operational records from the EBR-II, SRE, FFTF, and FERMI-I reactors. Of these reactors, only EBR-II has been added to the CREDO-II database although more reactors are anticipated to be added in the upcoming years. Furthermore, new relationships such as component images and schematics of system will be added in the near future to allow for future users of CREDO-II to gain a full understanding of the environmental conditions of components for these now decommissioned facilities.

2.3.NaSCoRD

Since a portion of the original CREDO database (referred to as CREDO-I) has been obtained, efforts are underway to unify it and CREDO-II into a single database. This combined database will be referred to as NaSCoRD, short for “Sodium System Component Reliability Database”. A general diagram of NaSCoRD is given as FIG. 5. Analysis tools were not included with the CREDO-I recovered files; the information retrieved is a direct reflection of the reports submitted to the CREDO project. The information currently in CREDO-II is similarly raw, having undergone only classification. Additional fields will be added to both databases to facilitate merging into NaSCoRD.

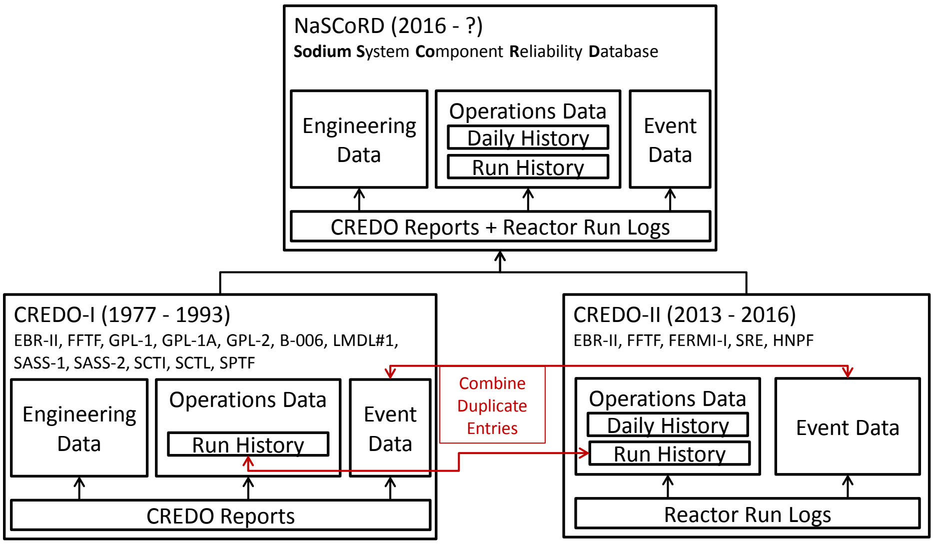

FIG. 5. Conversion diagram of the proposed NaSCoRD.

CREDO-II events will receive event bounding information in order to check for similarity with entries of occurrence date and resolution time in CREDO-I. This is necessary because events in the reactor run logs were not always given resolution dates. Two methods were used to bound resolution dates for events in EBR-II: run history and document. The run history method is applicable only to those events that required reactor shutdown, as it employs the reactor power history. When a shutdown (as evidenced by a minimal daily thermal power of 0) is seen immediately after the initial occurrence date, the lower bound for the resolution date is set as the day the reactor returns to power operations. The upper bound is set as the last reporting day of the operations log that mentions the resolution of the event.

The document bounding method is more rudimentary, and bounds resolution between the day after the initial event occurrence and the last reporting day of the operations log that mentions resolution. Of 950 events in CREDO-II for EBR-II, 733 do not have definite resolution dates and thus require bounding. The distribution of resolution date ranges determined using a combination of the methods is shown in FIG. 6. The history method is used for events that required shutdown, while the document method is used for all others. A significant number of events are bound within a 20 day range. The largest bin is around 45 days representing a few reactor logs that spanned approximately that length of time and included a large number of events without resolution date information.

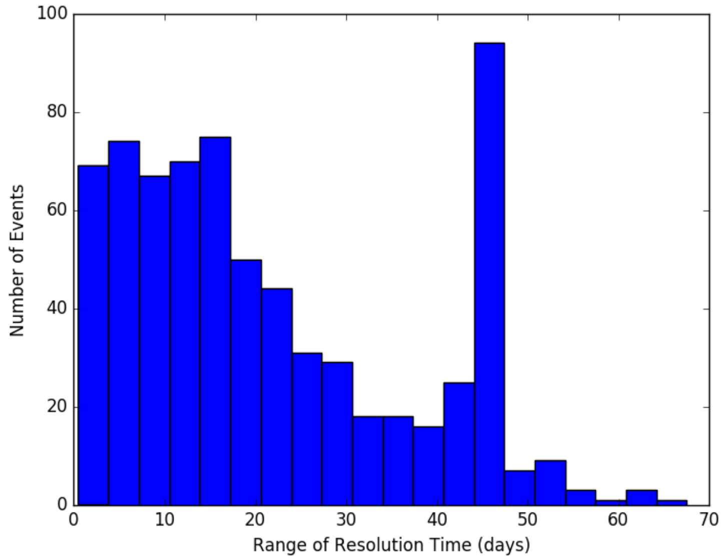

FIG. 6. Bounding of event resolution date for EBR-II using CREDO-II data.

A first pass using occurrence date and component type was performed to attempt to identify matching events for EBR-II between CREDO-I (537 events) and CREDO-II (950 events). Events whose occurrence dates were within 3 days of each other were presented to an analyst along with the component, system, and event narrative. This resulted in 219 potential matches. The analyst was then asked to confirm that the events are a match, confirm that the events are not a match, or mark the set for closer manual examination. Results were saved after each comparison so that the process could be repeated later with additional data. Eventually 66 CREDO-II events were matched with 76 CREDO-I events. These will be linked in NaSCoRD.

It is not certain that the events in CREDO-II completely envelop the EBR-II events in CREDO-I. Any CREDO-II event that cannot be matched with a CREDO-I event will be brought to into the NaSCoRD format with null values for data fields provided only by CREDO-I. The subset of these events with uncertain start or resolution times will be entered into NaSCoRD along with their document and reactor history bounding estimates. CREDO-I contains 63 fields for each event entry, in contrast to the 11 in CREDO-II. The fields in CREDO-I fully envelop those in CREDO-II, and so will be used as the template for events in NaSCoRD.

No daily operational data are included in CREDO-I; only run-based or interval-based data are presented. These will be merged with the run-based operational data in CREDO-II. These will be helpful in identifying gaps in knowledge of reactor history, particularly for FFTF. The operational data in CREDO-I largely envelop that available in CREDO-II. The primary exception is that CREDO-II includes electrical production and primary pump usage data, where available. These fields will be added to those in CREDO-I to create the run-based operational history in NaSCoRD.

3. Accessing the database

The CREDO databases reside on Microsoft SQL Server 2014 database servers. This is an industry recognized enterprise level database management system. Production versions reside on the Sandia External Collaboration Network (ECN). The production database server has 24x7 availability and support. Database backups are performed nightly with weekly backups sent to an off-site storage facility. Reporting for the CREDO-I and CREDO-II database is provided by Microsoft SQL Server Reporting Services (SSRS) 2014. This is an industry standard reporting environment that has been available since 2000. An initial set of reports for the CREDO-I database have been developed for initial user testing. The SSRS reports are rendered through Microsoft's SharePoint web application. By implementing the databases using standard Sandia hosting tools, a level of protection is afforded against accidental loss of access to the data.

The Sandia ECN is directly available through the internet; although it does require an account with a *userid* and *password* acquired from Sandia password control. Authorized users may acquire accounts and passwords through a Sandia sponsor, likely the corresponding author of this paper. The development environment for the CREDO databases is similar to the ECN but resides on a restricted network and is not available through the internet.

4. Utilization of the Database

The three databases described in this effort will eventually not only be able to provide basic event probabilities of components but also provide system engineers with vital information related to the design and function of future SFRs. The ability to quickly and effortlessly search for historical issues associated with various pipes, valves, sensors, and other components in sodium environments will allow future designers to ensure adequate operational safety in their designs. The capacity of past designs can be probed to identify and design around historical limitations for the benefit of future designs.

FIG. 7 shows such a plot from the original CREDO database. [10] This type of plot identifies the component failures that drive reactor unavailability for the SFRs EBR-II, FFTF, and JOYO. Through datamining with these types of unavailability plots, future designers can identify components whose failure drive unavailability and thus decrease revenue of the plant instead of simply identifying components which fail often but may not cause a reactor shutdown. Once identified, new designs or operating characteristics for these components can be identified and validated through testing programs before the SFR is constructed. This process has the potential for cost-savings above and beyond the costs of the database and can be updated with new component information as it is made available.

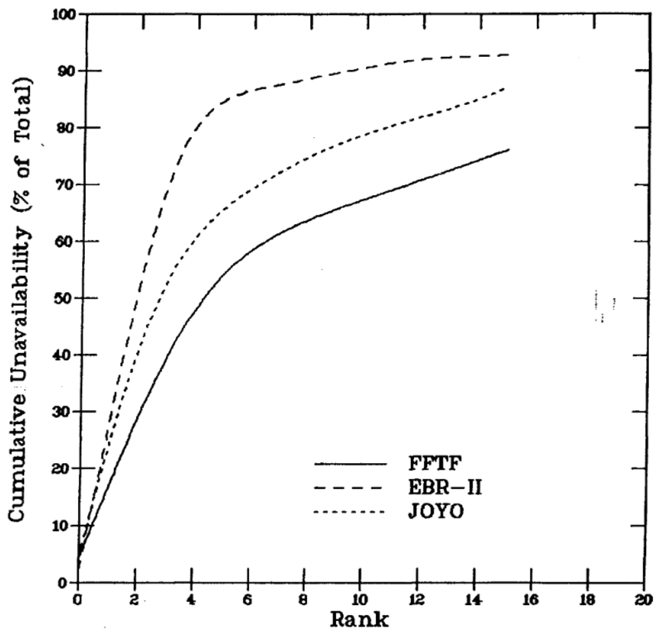

FIG. 7. Cumulative reactor unavailability as a function of rank order of reactor component from the CREDO database.[10] Note that the rank order is different for different reactors plotted.

5. Conclusions

After years of dormancy, the United States Government is standing up reliability databases to support future SFR development. Two databases, CREDO-II developed from operational documentation and CREDO-I reacquired from JAEA, are currently under active development at SNL. These development efforts are fulfilling different yet complementary roles as a comprehensive and near real-time record, CREDO-I, and a traceable and feature rich resource, CREDO-II. In the near future, CREDO-I and CREDO-II will be combined into NaSCoRD which will provide a unified platform to gain reliability and operational insights for SFRs.

6. References

[1] Task Group on Advanced Reactor Experimental Facilities, “Experimental facilities for Sodium Fast Reactor Safety Studies,” OECD NEA, NEA/CSNI/R(2010)12, 2011.

[2] W. Ivans, “The Current Nuclear Regulatory Environment: A PRISM Perspective,” M.S. Thesis, Department of Nuclear and Radiological Engineering, University of Florida, Gainesville, FL, 2006.

[3] M. S. Smith, J. D. Drischler, “The Centralized Reliability Data Organization (CREDO): Past, Present, and Future,” CONF-930116--8, International Topical Meeting on Probabilistic Safety Assessment, Clearwater Beach, FL, January 26-29, 1993.

[4] S. L. Painter, H. E. Knee, B. Humphrys, “CREDO Analysis: A Comparison of Liquid Metal and Water Valve Reliabilities,” International Conference on Nuclear Power Plant Aging Availability Factor and Reliability Analysis, San Diego, CA, July 3-13, 1985.

[5] T. F. Bott and P. M. Haas, “Analysis of Sodium Valve Reliability Data at CREDO,” CONF-790816--19, International Meeting on Fast Reactor Safety Technology, Seattle, WA, August 19, 1979.

[6] T. F. Bott, P. M. Haas, J. J. Manning, “Sodium Component Reliability Data Collection at CREDO,” CONF-790606-62, ANS Annual Meeting, Atlanta, GA, June 3, 1979.

[7] T. F. Bott, G.W. Cunningham, N.M. Greene, P. M. Haas, S.D. Hudson, H.E. Knee, J.J. Manning, “Development of the Centralized Reliability Data Organization (CREDO),” American Nuclear Society Meeting, San Francisco, CA, November 12, 1979.

[8] B. L. Humphrys, M. J. Haire, K. H. Koger, J. F. Manneschmidt, K. Setoguchi, R. Nakai, Y. Okubo, “An Examination of Reliability Critical Items in Liquid Metal Reactors: An Analysis by the Centralized Reliability Data Organization (CREDO),” Fast Breeder Systems: Experience Gained and Path Forward to Economical Power Generation, Kennewick, WA, September 13-17, 1987.

[9] D. H. Wood, M. S. Smith, J. D. Drischler, “Motor Operated Globe Valve Performance In a Liquid Sodium Environment,” CONF-920818--2, Bi-Annual Nuclear Energy Meeting of the American Nuclear Society and the American Society of Mechanical Engineers, San Diego, CA, August 23-26, 1992.

[10] K. H. Koger, M. J. Haire, B. L. Humphrys, J. F. Manneschmidt, K. Setoguchi, R. Nakai, “Assessment of Critical Component Unavailability in Liquid Metal Reactors,” ANS Summer Meeting, San Diego, CA, June 12-17, 1988.

[11] A.G. Cannon, A. Bendell, “Reliability Data Banks,” Elsevier Science Publishers, New York, NY, 1991.