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THE CENTRALIZED RELIABILITY DATA ORGANIZATION (CREDO)

ASSESSMENT OF CRITICAL COMPONENT UNAVAILABILITY IN LIQUID METAL REACTORS*

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ABSTRACT

The Centralized Reliability Data Organization (CREDO) is the largest repository of liquid metal reactor (LMR) component reliability data in the world. It is jointly sponsored by the U.S. Department of Energy (DOE) and the Power Reactor and Nuclear Fuel Development Corporation (PNC) of Japan. The CREDO data base contains information on a population of more than 20,000 components and approximately 1,500 event records. A conservative estimation is that the total component operating hours is approaching 2.2 billion hours. The work reported here focuses on the availability information contained in CREDO and the development of availability critical items lists. That is, individual components are ranked in prioritized lists from worst to best performers from an availability standpoint. Availability as used here is an inherent characteristic of the component and is not necessarily related to plant operability.

A major observation is that a few components have a much higher unavailability factor than the average. The top fifteen components contribute 93%, 77%, and 87% of the total system unavailability for EBR-II, FFTF, and JOYO respectively. Critical components common to all three sites are mechanical pumps and electromagnetic pumps. Application of resources to these components with the highest unavailability will have the greatest effect on overall availability.

All three sites demonstrate that low maintainability (i.e., long repair times), rather than unreliability (i.e., high failure rates), are the main contributors, by about a two-to-one margin, to liquid metal system unavailability.

1.0 INTRODUCTION

The Centralized Reliability Data Organization (CREDO) is an advanced reactor component reliability, availability, and maintainability (RAM) data base and data analysis center located at the Oak Ridge National Laboratory (ORNL). It is sponsored by the U.S. Department of Energy (DOE) and Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC). Since 1979, CREDO has focused on collecting data from the Fast Flux Test Facility (FFTF) and the Experimental Breeder Reactor-II (EBR-II).

In addition, data has also been collected at several important U.S. test facilities, including the test loops of the Energy Technology Engineering Center (ETEC) and Westinghouse's Advanced Energy System Division. In January 1985, a Specific Memorandum of Agreement concerning CREDO was reached between the U.S. DOE and Japan's PNC. In general, the agreement called for a mutual cost-sharing and data-sharing program. More specifically, it was agreed that PNC would provide data from their JOYO liquid metal reactor and from four test facilities located at their O-Arai Engineering Center. In addition, PNC would share in the cost of CREDO system development. DOE/CREDO would provide to PNC a parallel CREDO data base, including U.S. liquid metal reactor component data, through the life of the agreement. With the inclusion of data from PNC, the CREDO data base currently contains more than 20,000 engineering records (component description records), 1,500 event/failure records, and approximately 2.2 billion component operating hours.

The CREDO system is capable of producing a variety of reliability, availability, and maintainability analyses. A detailed description of CREDO - the input data forms, the data base management system, its standardized output, and specialized statistical software - has been provided elsewhere.[1-5] The purpose of this paper is to describe one such analysis: the development of availability critical items. A prioritized listing of items whose unreliability or low maintainability critically affects system unavailability will be presented such that an increased awareness on the dependency of these items can maximize the availability of liquid metal reactors.

2.0 AVAILABILITY CRITICAL ITEMS

This paper develops availability critical items based on the availability information contained in the CREDO data files as they existed during the spring of 1987. The CREDO data base does not track the performance of every reactor component. Only those components which are liquid metal specific, associated directly with a liquid metal environment, contained in systems which interface with liquid metal environments (e.g., cover gas or purification systems), and important safety-related components are tracked. Actual operational experiences are used to establish the critical items for liquid metal reactors in the United States and Japan.

An importance function, or ratio is used in preparing an availability critical items list. The importance function, I, is defined:

(1) $$I_i = \frac{\text{unavailability of item } i}{\text{unavailability of system}}$$

Assuming an exponential failure density distribution and a high system availability, equation 1 can be approximated by:

(2) $$I_i \cong \frac{\lambda_i \quad \tau_i}{\sum_{i=1}^{N} \lambda_i \quad \tau_i}$$

where

λ_i = the event (failure) rate for item i

τ_i = the mean time to repair for item i assuming a log-normal distribution

I_i = importance function for item i

i = the item of interest.

N = the number of components tracked by CREDO at a given reactor site

In forming the availability critical items list, the calculated values of the importance function are prioritized or ranked from highest to lowest numbers. Those items near the top of the list are those which have the worst performance relative to the unavailability for the system. Those near the bottom of the list exhibit the best availability. Identification of common traits of components near the top of the list compared to those near the bottom may lead to actions which will improve their performance and their subsequent placement lower in the hierarchy of the availability critical items list. Note that in the context used here, system does not mean a grouping of plant components such as the plant protection system. Instead, it is the population of liquid metal-related components tracked by CREDO for a given reactor site.

3.0 RESULTS AND OBSERVATIONS

Tables 1, 2, and 3 present the availability critical items lists for EBR-II, FFTF, and JOYO reactors for those components whose performance is tracked by CREDO. A brief effort is made to evaluate the effect of the event in the column entitled "consequence." An entry of '1' in this column means the reactor was shut down and there were safety implications (e.g., the component involved was part of a safety system) associated with the shutdown. An entry of '2' indicates that the plant was shut down and there were minor, or no safety implications. An entry of '3' means that the plant was not shut down but there was a major impact from the event, for example, a system might be lost. An entry of '4' indicates that the plant was not shut down and the impact of the event was minor or even a nuisance event. It should be noted that references to "plant shutdown" are used not only if the reactor was at power and had to be shut down because of the event, but also if the reactor was not operating when the event occurred and could not be restarted until the event was corrected. Thus, availability as used here is an inherent characteristic of the component and is not necessarily related to plant operability.

A few components have a much higher unavailability factor than the average, as shown in Figure 1. This figure is a plot of cumulative unavailability versus the rank of a component in the critical items list. The curves illustrate that the first fifteen components for EBR-II, FFTF, and JOYO contribute 93%, 77%, and 87% of the total system unavailability, respectively. System as used in this sense is the cumulative unavailability for all components whose performance is tracked by CREDO for each reactor site. Tables 1, 2, and 3 identify particular reactor systems. Thus, even though there are several hundred events for each reactor, a few components dominate the total unavailability.

Table 4 shows the contribution of the unavailability of the top ranked generic components to the total unavailability of those components tracked by CREDO at each reactor. Problems with mechanical pumps and electromagnetic pumps are common to all sites. For each reactor, more than 93% of the components whose operational performance is followed by CREDO have not failed. For the components that have failed, the mean failure rate at EBR-II, FFTF, and JOYO are respectively, 2.1E-05, 4.5E-05, and 3.5E-05 failures per hour. For the failures at each reactor, 95% of the failure distribution lies within a factor of 5 around the mean failure rate. The components with failure rates greater than 5 times that of the mean were identified in another study that generated reliability critical items lists.[7] In addition, approximately 90% of the repair times of the failed components are less than 200 hours, 55 hours, and 45 hours for EBR-II, FFTF, and JOYO, respectively. Those components with the longest repair times were identified in another previous study that generated maintainability critical items lists.[6]

Table 4 also shows that mechanical pumps and gas movers are the primary availability problems at EBR-II, again only for those components tracked by the CREDO data base. For FFTF, mechanical pumps, rupture devices, and control rod drive mechanisms are of primary availability concern. Mechanical pumps are the dominate contributors to unavailability at JOYO. It should be noted at this point that failures for motors associated with the primary mechanical pumps are included in the mechanical pump category.

Since availability is dependent on reliability and maintainability, an effort is made to determine which of these factors controlled the unavailability of each component. In Tables 1, 2, and 3, the Rel./Maint. column provides either an 'R' if the component has a high failure rate or an 'M' if a long restoration time was required after the component failed. Whether a component is primarily influenced by reliability or maintainability is obtained from reliability[7] and maintainability[6] critical items lists. For example, a component on the availability critical items list which also appears on the reliability critical items list, but not on the maintainability critical items list, is influenced primarily by reliability. The percentage of total system unavailability which is controlled by unreliability or by low maintainability for each site is shown in Table 5. This table indicates that maintainability influences the availability of components exposed to the liquid metal environment by about a two-to-one margin over the component's reliability.

Judging from the narrative entries on the CREDO event data collection forms, most efforts to improve plant availability are directed at preventing the recurrence of the fault and not at reducing the recovery time. This implies that a greater likelihood of increasing reactor system and plant availability can be achieved by emphasizing rapid recovery from events rather than the elimination of component failures.

4.0 SUMMARY

The critical items as described here are for those components whose failure has the potential to affect the ability of a reactor system or plant to perform its functional requirements. An availability critical items list is a prioritized ranking of components whose unreliability or low maintainability contributes to system unavailability. Tables 1, 2, and 3 display the availability critical items for EBR-II, FFTF, and JOYO, respectively. The components at the top of the list have the highest unavailability and therefore contribute most to unavailability for those reactor components contained in CREDO. The total number of recorded events for EBR-II, FFTF, and JOYO is 366, 484, and 220 respectively. These tables present only 15 of the top individual components whose events result in the lowest availability. These 15 components are the major contributors to system unavailability.

In comparing Tables 1, 2, and 3 with Figure 1, specific components which contribute most to low performance are a mechanical pump in the Primary Reactor Heat Transport System at EBR-II, a mechanical pump in the Primary Reactor Heat Transport System at FFTF, and a mechanical pump in the Secondary Reactor Heat Transport System at JOYO.

Table 4 indicates problems of primary concern for all three sites are mechanical pumps. These components contribute 52%, 31%, and 60% to system unavailability at EBR-II, FFTF, and JOYO respectively.

Table 5 shows that maintainability has about a two-to-one influence over reliability on the availability of components in a liquid metal environment. These results indicate that more attention to the rapid, effective restoration of failed components would have a greater impact on availability than a reduction of component failure rates.

The identification of those components believed to be critical from the viewpoint of reliability, availability, and maintainability is an opportune way to bring the importance of those items to the attention of plant management. The application of critical items lists to deal with key availability areas can become an invaluable management tool. It is by being aware of those components which contribute most to low performance that allows the effective application of limited resources to areas where it can be most beneficial.

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Table 1. EBR-II Availability Critical Items

Rank	Component	Reactor System	Consequence	No. of Events	Event	Rel. or Maint. Controlled
1	mech pump	Prim Reactor Heat Transport	2	3	high KW demand	M
			2	1	excessive vibration	
			2	1	pump seized	
			4	1	gas leak	
			2	1	hydrocarbons in sodium	
2	mech pump	Prim Reactor Heat Transport	2	3	pump seized	M
			2,4	3	high KW alarm	
3	gas mover	Gas Cooling	3	2	erratic operation	R
			3	1	excessive noise	
			3	2	excessive vibration	
4	gas mover	Gas Cooling	3	6	excessive vibration	R
			3	26	excessive noise	
			3	1	seized	
			3	2	supply breaker tripping	
			3	2	turbine stopped running	
5	cold trap	Auxiliary Liquid Sodium	2	5	plugged	M
			2	2	unrecorded event	
6	valve	Auxiliary Liquid Sodium	3	6	operator seal failure	M
			3	2	failure to open	
			3	1	bellows failure	
			3	1	shaft seal failure	
			3	1	operator failure	
7	em pump	Sec Reactor Heat Transport	2	1	sodium leak	M
			2	1	indicator failure	
8	heat exch	Sec Reactor Heat Transport	2	1	abnormal noise	M
9	plug meter	Impurity Monitoring	3	5	bellows failure	R
10	cold trap	Auxiliary Liquid Sodium	2	4	plugged	M
			2	1	unrecorded event	
11	cold trap	Inert Gas	2	9	argon pressure high	R
			2	2	flow restricted	
12	rupture dev	Sec Reactor Heat Transport	2	1	rupture disc failure	M
			2	3	rupture disc leak	
13	em pump	Impurity Monitoring	2	1	pump tripped	M
			2	1	unrecorded event	
14	em pump	Auxiliary Liquid Sodium	4	1	cooling water blockage	R
15	crdm	Plant Control	3	1	sense rod stuck	M
			2	1	jaws stuck open	
			2	1	failure to drive	

NOTE: An electric heater was removed from list due to difficulty in comparing failures on demand and failures to run.

Table 2 FFTF Availability Critical Items

Rank	Component	Reactor System	Conse-quence	No. of Events	Event	Rel. or Maint. Controlled
1	mech pump	Prim Reactor Heat Transport	4	2	seal leak	M
			4	2	controller failure	
			3	1	pump bound	
2	rupture dev	Inert Gas	4	1	breach in disc	R
3	crdm	Reactor Shutdown	4	2	rod sequencing card	M
			4	2	incorrect scram	
			4	2	fuse blown	
			4	1	Na frost on shaft	
4	mech pump	Prim Reactor Heat Transport	2,4	3	worn brushes	M
			4	1	bad bearings	
			4	1	abnormal flow	
			4	1	high vibration levels	
			2	1	bad relay	
			4	1	gear box leak	
5	mech pump	Prim Reactor Heat Transport	2,3	2	pump overspeed	M
			3	2	pony motor tripped	
			2	2	excessive slip ring wear	
			2	1	loss of flow	
			4	1	alarm malfunction	
6	gas mover	Inert Gas	3	2	compressor trip	R
			3	1	low compressor flow	
			3	1	low oil pressure	
7	gas mover	Inert Gas	4	4	diaphragm leak	M
			4	1	pressure limiter failure	
			4	1	breaker trip	
			4	1	low lube oil	
8	em pump	Auxiliary Liquid Sodium	2	1	sodium leak	M
			4	1	controller out of adjust	
9	cold trap	Fuel Failure Monitoring	4	1	lifting lug crack	R
10	cold trap	Fuel Failure Monitoring	4	1	lifting lug crack	R
11	cold trap	Fuel Failure Monitoring	4	1	lifting lug crack	R
12	gas mover	Inert Gas	4	1	oil leak	M
			4	1	removed filter	
			4	1	replaced blower	
13	nn sensor	Impurity Monitoring	4	2	spurious alarm	R
			4	1	tube plugged	
14	gas mover	Inert Gas	4	1	oil leak	M
			4	1	removed filter	
			4	1	replaced blower	
15	mech pump	Sec Reactor Heat Transport	4	2	oil seal cocked	M
			4	4	controller failure	
			4	1	defective brushes	
			4	1	unrecorded event	

NOTE: A combustion turbine for emergency power generation, with four events, was removed from list due to difficulty in comparing failures on demand and failures to run.

Table 3. JOYO Availability Critical Items

Rank	Component	Reactor System	Consequence	No. of Events	Event	Rel. or Maint. Controlled
1	mech pump	Sec Reactor Heat Transport	4	5	abnormal sound	M
			2	2	excessive brush wear	
			4	1	oil (grease) leak	
			2	1	abnormal current	
2	mech pump	Lube Oil	4	2	oil leak	R
			4	1	abnormal pressure	
			4	1	abnormal noise	
3	mech pump	Sec Reactor Heat Transport	4	1	abnormal sound	M
			4	1	oil leak	
			4	1	decreased resistance	
			4	1	worn brushes	
4	em pump	Auxiliary Liquid Sodium	2	4	failure to start	R
5	mech cntl device	Sec Reactor Heat Transport	3	3	stuck or slow vanes	R
			3	1	vanes suddenly opened	
6	detector	Flux Monitoring	3	1	false indication	M
7	mech pump	Lube Oil	4	1	oil leak	R
			4	1	abnormal pressure	
			4	1	abnormal noise	
8	mech cntl device	Sec Reactor Heat Transport	4	1	no indication	M
			3	1	stuck vane	
9	nn sensor	Auxiliary Cooling	3	3	short circuit	M
10	mech cntl	Sec Reactor Heat Transport	3	2	vanes fail to close	R
11	em pump	Auxiliary Cooling	2	2	tripped	R
			3	2	no voltage change	
12	nn sensor	Sec Reactor Heat Transport	3	2	short circuit	M
13	nn sensor	Sec Reactor Heat Transport	3	2	short circuit	M
14	valve	Auxiliary Liquid Sodium	4	1	twisted bellows	M
15	em pump	Auxiliary Liquid Sodium	3	1	decreasing flow	R
			3	1	tripped	
			3	1	lack of control	

Table 4. Percent of Total Unavailability for Highest Ranked Components*

Component	EBR-II	FFTF	JOYO
mechanical pumps	51.9	31.2	58.1
gas movers	29.6	8.5	--
electromagnetic pumps	2.6	2.2	8.7
mechanical control devices	--	--	9.9
nonnuclear sensors	--	--	5.3
nuclear detectors	--	--	3.2
cold traps	4.0	6.4	--
rupture devices	--	14.1	--
control rod drive mech.'s	--	12.1	--

*Only components that contributed more than 2% of total unavailability are listed here.

Table 5. Reliability/Maintainability Controlled

	EBR-II	FFTF	JOYO
R	34%	33%	38%
M	66%	67%	62%
	100%	100%	100%

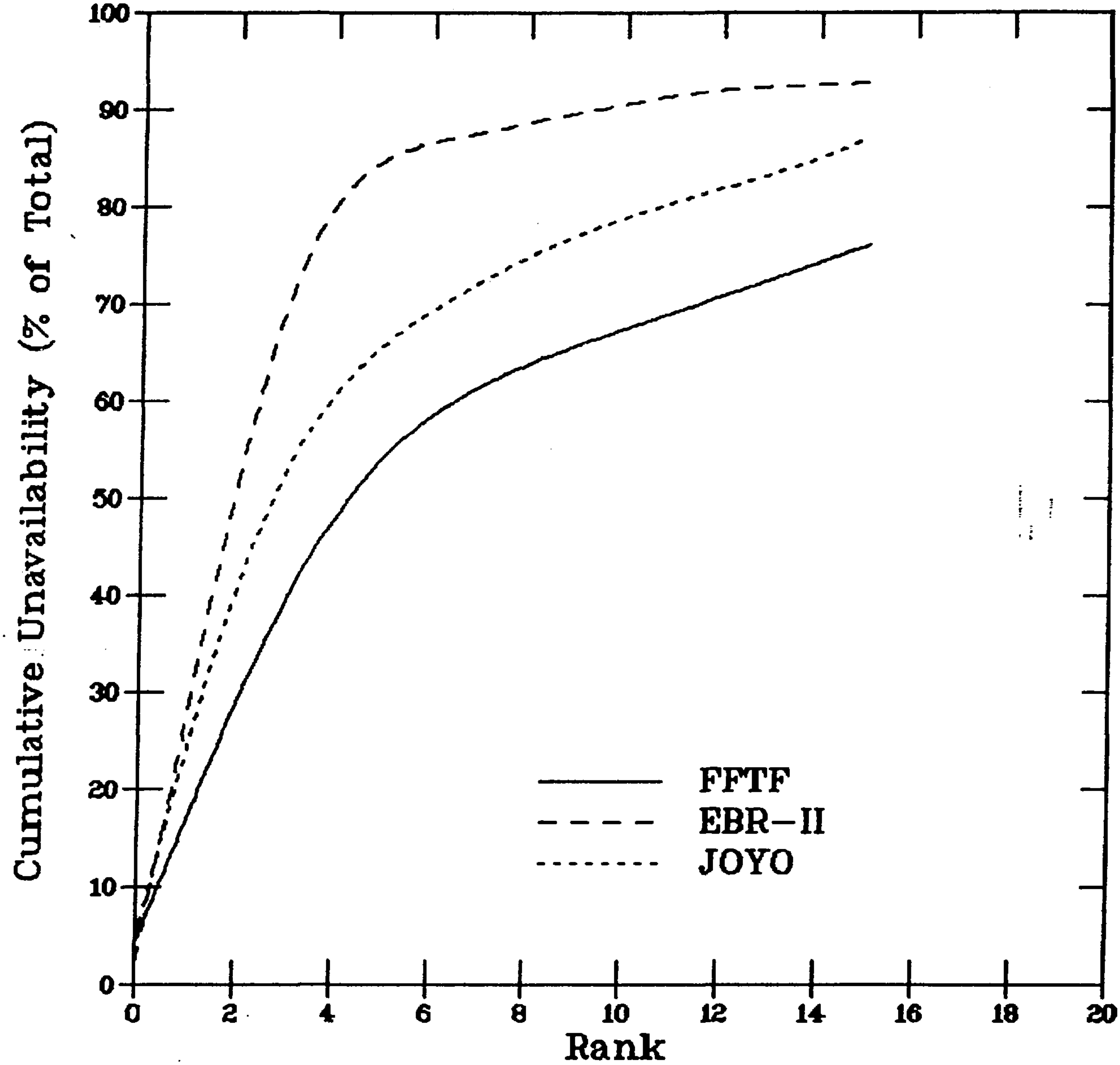

Fig. 1: Cumulative unavailability as a function of critical item rank