THE CENTRALIZED RELIABILITY DATA ORGANIZATION (CREDO)

An Examination of Maintenance Activities in Liquid Metal Reactor Facilities: An Analysis by the Centralized Reliability Data Organization (CREDO)*

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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 database contains information on a population of more than 21,000 components and approximately 1,300 event records. Total experience is approaching 1.2 billion component operating hours. Although data gathering for CREDO concentrates on event (failure) information, the work reported here focuses on the maintenance information contained in CREDO and the development of maintenance critical items lists. That is, components are ranked in prioritized lists from worse to best performers from a maintenance standpoint.

It was found that the restoration of only a very few components contributes to the majority of downtime: The five highest ranked equipment components compose 56% of the total downtime in the Experimental Breeder Reactor (EBR-II), 46% in the Fast Flux Test Facility (FFTF), and 41% in the Experimental Fast Reactor (JOYO). Although the dominate mode of failure differs, mechanical sodium coolant pumps are primary contributors to restoration time for all three reactors.

Long repair in mechanical components are primarily due to the inaccessibility and the awkwardness of dealing with large equipment. The environment in which the equipment is located, the inability to always detect deteriorating component performance, slow diagnosis of electrical failures, and long retest times are other contributors to low maintainability. Designing for maintenance during early facility design phases would alleviate many problems concerning accessibility and environment. Better non-intrusive surveillance electronics would enable earlier detection, better diagnosis, and faster retest times.

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1.0 INTRODUCTION

The Centralized Reliability Data Organization (CREDO) is an advanced reactor component reliability, availability and maintainability data base and data analysis center funded by the U.S. Department of Energy's (DOE) Office of Technology Support Programs and Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC). Since its establishment at the Oak Ridge National Laboratory in 1978, CREDO has focused on the collection of component data from existing U.S. liquid metal reactors (EBR-II and FFTF) and various test loop facilities (e.g. the test loops of the Energy Technology Engineering Center, ETEC). In January 1985, the U.S. DOE and Japan's PNC entered into a Specific Memorandum of Agreement to share the collection, analysis, and dissemination of advanced reactor reliability, availability and maintainability data and information. In this agreement, the U.S. data files and data base management system were given to PNC where it is presently operating as the FREEDOM data base. In return, PNC supplied data from Japan's Experimental Fast Reactor (JOYO), from four test loops located at their O-Arai Engineering Center, and funding to aid further CREDO development. Japanese data was fully incorporated into the CREDO data base by late

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1986. Presently, the combined data bases contain more than 21,000 engineering records and 1,300 event records. Total recorded operating experience is approaching 1.2 billion component operating hours.

The CREDO data base management system categorizes and assimilates the massive amount of data and information collected in an iteractive storage and retrival mechanism. This capability allows for the generation of a number of important reliability, availability and maintainability performance measures and forms the basis for carrying out specialized analyses. One such analysis is described here; the development of maintenance critical items.

Critical items are those items whose failure could significantly affect the ability of a system or unit to perform its function effectively or safely. A maintenance critical items list is a prioritized listing or ranking of those events whose restoration, upon failure, contribute to low system maintainability. Thus, those components near the top of the list are the most difficult to maintain and contribute most to system unavailability. Knowing those components which contribute most to low system performance allows the allocation of limited (or even scarce) resources to those problem areas where their application will have the greatest benefit. This work develops and characterizes the maintenance critical items for the EBR-II, FFTF and JOYO liquid metal reactors, for the components of those reactors contained in the CREDO data base.

2.0 CREDO DESCRIPTION AND STRUCTURE

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.[1,2,3,4,5] A summary description is given here for completeness.

The purpose of CREDO is to provide a centralized source for accurate, up-to-date data and information for use in reliability, availability and maintainability analyses of advanced reactors. To accomplish this task, comprehensive and continuous data collection is carried out at various reactor sites and test facilities. CREDO is a component-based system, i.e., data focus is on a specific equipment item identified as a component within a given system. Components are assigned to a specific system and general data related to system operation and failure is obtained. A set of 45 generic component categories, given in Table 1, that are representative of all components found at any reactor site, are defined.

Data reported are categorized into three types:

1. **Engineering Data**. The engineering data file provides a unique description of each component. This file consists of design and operating characteristics for each component for its particular application in its unit or system. Engineering data are usually reported once per component, preferably prior to its initial operation and updated when necessary. When a fault occurs, this engineering data is correlated with the event report, in analysis of the root cause of the occurrence. Engineering data can be updated to account for varying conditions or usage through the

component lifetime, or, can be completely revised to reflect major system changes.

2. **Operating Data.** The operating data consists of a set of chronological sequential reports which provides a profile of the accumulated operating history of the reporting unit. Each operating data report form gives the hours of unit operation in previously specified modes. Combining unit operating factors or duty cycle for each mode that is specified on the component engineering data record permits accurate estimates of actual component operating hours.

3. **Event Data.** The event data file contains detailed data of reportable occurrences for components being tracked by the CREDO system. These data include a description of the event, method of detection, failure mode, failure cause, corrective action, effects on related systems, human interaction, most recent maintenance, etc. Narrative sections have been placed on the Event Data Reporting Form to gain additional insight to circumstances surrounding a particular event.

The combination of information from the engineering, operating and event files allows the calculation of a number of parameters such as failure rate, mean-time-between-failures, mean-time-to-repair, etc. One of CREDO's outstanding characteristics is the detail to which data searches can be structured. It is possible to conduct data searches with all keyword qualifiers and design parameters. The CREDO data base management system categorizes and assimilates the numerous information collected in an iteractive storage and retrival mechanism which can, upon demand, produce organized output of statistical significance. The output includes not only basic reliability, availability and maintainability measures of performance, but can include enhanced statistical analysis capabilities based on a wide range of functions and distribution of failure models.

Until recently, most of the CREDO effort has concentrated on developing a data base management system and on collection, evaluation and processing of the engineering, operating and event history. The operating history of these components will continue to be tracked along with any changes in engineering data, but this is a relatively small effort compared to the past development of CREDO. The CREDO staff is now becoming more involved with the analyses of data already collected. Also, efforts are now focusing on becoming an international center for the collection and dissemination of reliability, availability and maintainability data.

3.0 MAINTENANCE CRITICAL ITEMS

The identification of items in the system design believed to be critical from the standpoint of reliability, availability or maintainability is an excellent way to bring the importance of reliability matters into central focus. A critical items list is a valuable management tool for identifying the most important reliability problems. In this work, critical maintenance lists are developed. These lists rank or prioritize those components whose repair upon failure contributes most to system low maintainability. As is usually customary, the duration of an outage is a measure of maintainability. Knowing those components which contribute most to low system performance allows the allocation of limited, or scarce, organizational resources to those problem areas where their application will have the greatest benefit.

This paper develops maintenance critical items based on the maintainability information contained in the CREDO data files as they existed during the summer of 1986. Actual operational experiences are used to establish the critical items for liquid métal reactors in the United States and Japan.

An importance function, or ratio, is used in preparing a maintenance critical items list. The importance function, I, is defined

$$I_i = \frac{\text{mean time restore for item i}}{\text{mean time restore for the system}} \qquad (1)$$

Assuming an exponential failure density distribution, a high system availability, and the operating time which is long relative to the repair times, equation 1 can be approximated by

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

where

τ_i	=	the mean time to repair for item i
λ_i	=	the event (failure) rate for item i
I	=	importance function
N	=	the number of items in the system
i	=	the item of interest

In forming the maintenance 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 the items which have the worst performance relative to the time to return to normal operation. Those near the bottom of the list are the easiest to maintain. An investigation of common traits of components near the top of the list compared to those near the bottom may lead to a reduction of their influence on poor system performance and their subsequent placement lower in the hierarchy of the critical maintenance list.

4.0 RESULTS AND OBSERVATIONS

Tables 2, 3 and 4 give the critical maintenance items for EBR-II, FFTF and JOYO reactors for those components whose performance is tracked by CREDO. Some critical items have multiple occurrences of the same event. There are three reasons for this: (1) a design improvement in one item is implemented in companion items; (2) it is decided that it is not cost effective to correct the root cause of the failure (e.g. the item is added to the preventive maintenance program); and (3) multiple events occur before the root cause is diagnosed and fixed. A brief effort is made to evaluate the consequence of prolonged restoration time in the column entitled "unit loss". If the reactor was at power and had to be shutdown because of the event, or, if the reactor could not be restarted until the event was corrected, a "yes" (Y) is entered in the column. A "no" (N) means that the system is fault tolerant and that the reactor did not have to be shutdown because of the event. Also, a "no" may be entered if an uncorrected event will not prevent restart (for those events detected during regularly scheduled downtime inspections.)

Figure 1 is a plot of the cumulative restoration time as a function of critical item rank. The curve for EBR-II reactor is higher than those for the other two reactors because the top ranked events consume a larger proportion of total downtime for EBR-II than for FFTF or JOYO. The restoration times at EBR-II are slightly longer than at FFTF and restoration times at JOYO are the shortest. Repair times at the JOYO reactor are more evenly distributed and monotonically decreasing in time length with no abrupt discontinuities. No absolute comparisons are made because the maintenance data, as it now exists in CREDO, gives restoration times (the time interval between fault detection and recertification) for EBR-II and FFTF, and repair times (the time period for correction or replacement of faulty equipment) for JOYO. Repair time is assumed proportional to restoration time. Comparisons with normalized or relative numbers (e.g. percentages) as described here should be valid, however. There does not appear to be any dependence between length of restoration time and chronological time since reactor startup for any of the three reactor sites.

As shown in Figure 1, the five highest ranked components contribute 56% of the restoration time in EBR-II, 46% in FFTF, and 41% in JOYO. There are several hundred events for each reactor. Thus, a very few items dominate the total restoration time for each liquid metal reactor site.

The number of events recorded in the CREDO data base for EBR-II, FFTF and JOYO operations are 336, 339 and 200 respectively. JOYO maintenance events seem to be more electrical and electronic related, but this may be the result of different data collection emphasis among sites. Of the highest ranked 20 equipment items, mechanical coolant pumps are the largest contributor to restoration time at all three sites. It should be noted that the mechanical coolant pumps have different dominate modes of failure for each site (JOYO-electric motors; EBR-II-bowed shaft; FFTF-seal leak). These conclusions are illustrated in Table 5. The design for maintenance for these pumps should be carefully examined in future reactors.

Many specific recommendations have been made to each reactor site manager regarding individual events. Some of these are shown in the "maintenance significance" column of Tables 2, 3, and 4. Rather than reciting corrective actions for individual faults, some general observations are given here.

a. By far, the primary cause of long restoration times for mechanical equipment is the general inaccessibility of the equipment. A corollary to this is the awkwardness of large items, the lack of maneuvering room, and lay-down space. Little can be done to rectify this in currently operating plants. But, this conclusion emphasizes the need to design for maintenance during the earliest facility design phases.

b. Environmental constraints (sodium draining and cleaning, and waiting for radioactivity decay) is another major contributor to long restoration times. Again, choices which lead to these constraints took place during the conceptual design phase of the facilities.

c. Early, or imminent, detection of faults can reduce substantially restoration times. Catastrophic failures, e.g., a large sodium leak versus a small one, are more difficult to repair. Longer restoration times result from unexpected occurrences with their accompanying unpreparedness in terms of procedures, spare parts, and training. Better non-intrusive surveillance techniques are needed to monitor deteriorating performance and to warn of incipient failure.

d. Once failure has occurred, rapid diagnosis of the fault is required for short restoration times. Most diagnostic problems occur in electrical and electronic equipment. Better diagnostic techniques would often shorten the time required to restore a failed item to operation.

e. Long retest times (i.e. confirmation that the fault is corrected) are sometimes a significant contributor to the length of restoration times.

f. The spare part inventory, and an optimized appropriate number of spare parts per component, is important.

g. The administrative overhead associated with a repair may be a significant contributor to long restoration times. The more people involved, the more support groups (safety, QA, etc.) and organizations involved, the longer will be the restoration time. The administrative overhead contribution to downtime is related to the amount of forewarning of occurrence (item c): The ability to monitor deteriorating performance enables advanced preparation for fault correction.

Whereas the above items a and b are set during early design, attention to items c through g can improve the maintainability of presently operating facilities.

Judging from the narrative portions of the CREDO event form, most efforts to improve plant availability are directed at preventing the re-occurrence of the fault and not at reducing the recovery time. Eliminating failures is an effective way of improving availability. However, it must be accepted that failures will occur in complex systems containing large numbers of components, even though each component may have a small rate of failure. The rapidity of their recovery is another important way of increasing system and plant availability. Given its existence, more emphasis should be placed on means of reducing the length of restoration time.

5.0 SUMMARY AND CONCLUSIONS

The EBR-II, FFTF and JOYO maintenance information contained in the CREDO data base is analyzed in the development of maintenance critical item lists. These lists are a prioritization, or ranking, of those events whose repair upon failure contributes most to low plant maintainability. Of the several hundred events recorded in CREDO for each reactor system, very long downtimes were centered in only a very few components. Thus, the concentration of resources on the causes of those with long restoration times will result in the greatest benefit.

Mechanical coolant pumps dominate the critical items lists and are the primary contributor to restoration time. Repair of electrical and electronic equipment is a significant contributor to downtime. The primary causes of long restoration times for mechanical components are that equipment is generally inaccessible, large and awkward to maneuver. The appropriate spare part inventory is essential for rapid restoration. The environment in which the failed item operates often slows repair. Better detection of incipient failures and diagnosis of electrical and electronic faults once they occur would speed restoration. Designing for maintenance and consideration of operating environment during early facility design phases has the potential for greatly reducing maintenance costs. In presently operating facilities, reduced restoration times would result from improved condition monitoring and research of better surveillance (detection and diagnosis) equipment.

Most of the emphasis to improve system and plant availability has been placed on removing the root causes of failure. Faults are inevitable and more emphasis should be placed on improving the means of reducing restoration times.

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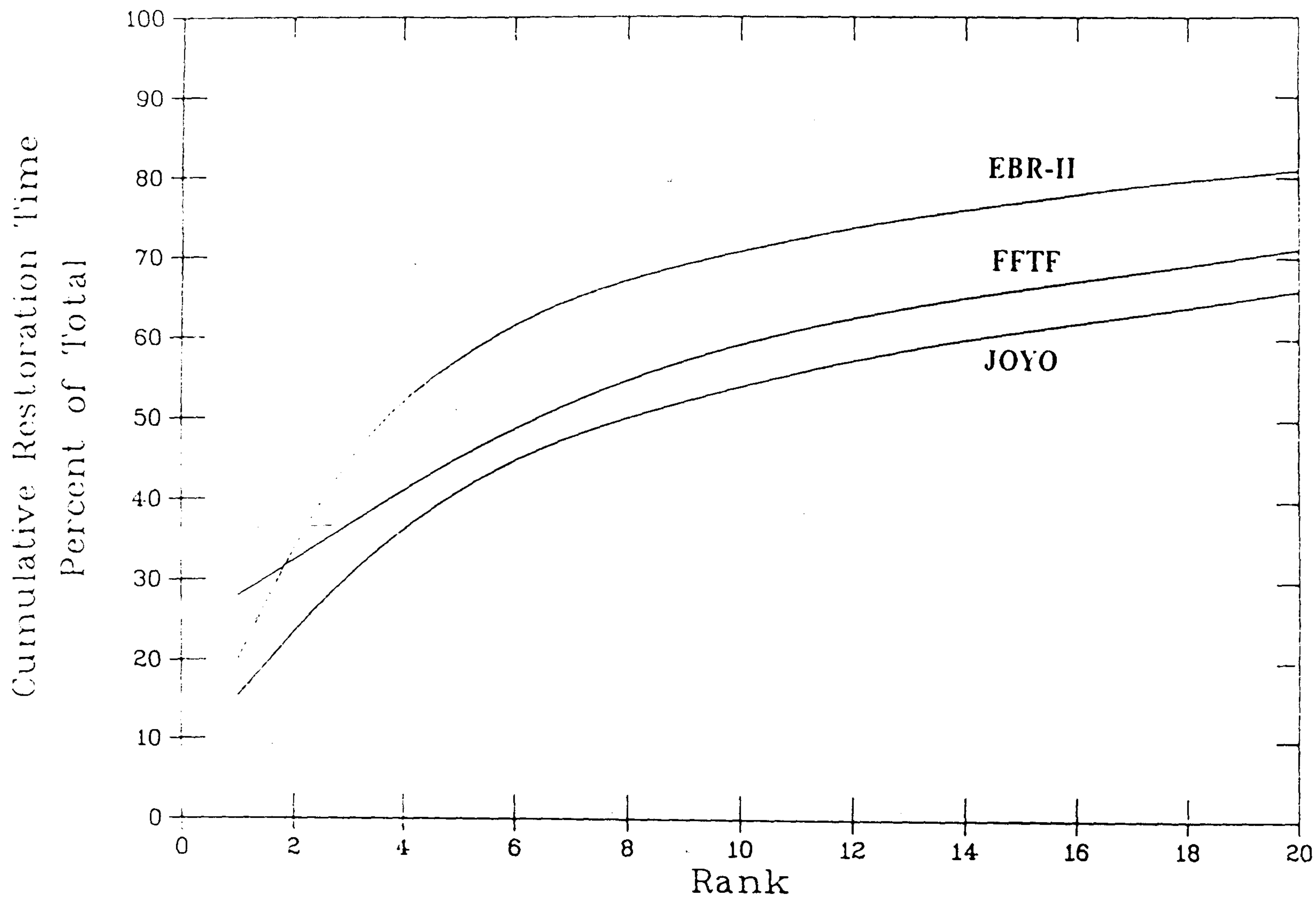

Figure 1. Cumulative restoration time as a function of maintenance critical item rank.

TABLE 1. CREDO COMPONENT LIST

ANNUNCIATOR MODULES	LOGIC GATES
BATTERIES	MECHANICAL CONTROL DEVICES
CIRCUIT BREAKERS AND INTERRUPTERS	MECHANICAL PUMPS
COLD TRAPS AND VAPOR TRAPS	MOTORS
CONTRACTORS AND STARTERS	NONNUCLEAR SENSORS
CONTROL ROD DRIVE MECHANISMS	NUCLEAR DETECTOR
DEMINERALIZERS	PENETRATIONS
ELECTRICAL BUSES	PIPE AND FITTINGS
ELECTRICAL CONDUCTORS	PLUGGING METERS
ELECTRIC AND ELECTRICAL CONNECTORS	POWER SUPPLIES
ELECTRIC HEATERS	PRSSURE VESSELS AND TANKS
ELECTROMAGNETIC PUMPS	REACTOR CONTROL RODS
FILTER/STRAINERS	RECOMBINERS
FUSES	RECORDERS
GAS DRYERS	RELAYS
GAS MOVERS	RUPTURE DEVICES
GENERATORS	SIGNAL MODIFIERS
HEAT EXCHANGERS	SIGNAL TRANSMITTERS
INDICATORS	SUPPORT AND SHOCK DEVICES
INSTRUMENT CONTROLLERS	SWITCHES
INTERNAL COMBUSTION ENGINES	TRANSFORMERS
LIQUID RHEOSTAT	TURBINES
	VALVES

Table 2. EBR-II Maintainability Critical Items

Rank	Component	System	No. Events	Unit Loss	Event	Maintenance Significance
1	mech. pumps	PRIM RX HT	2	Y	shaft found bowed	initial reactor testing
2	piping	SEC RX HT	1	N	broke clamp in fill tube of int. heat exchanger	develop remote TV inspectio
3	EM pumps	SEC RX HT	1	Y	cracks in duct	develop sawing, welding technique
4	cold traps	AUX LIQ NA	7	N	traps reach saturation	change design, increase replacement interval
5	control rod drive	PLNT CONT	13	Y	sense rod and jaw bellows failure	install new remote handling container
6	bus bar	PRIM RX HT	1	Y	bus bar eroded	designed technique to weld SS to copper
7	electric heaters	P A EQ HEAT	6	N	burned out heating element	original design did not allow for element replacement
8	filter	GAS COOL	2	N	molecular seive plugged	sleeve redesigned with flange to facilitate maintenance
9	EM pump	AUX LIQ NA	1	N	high resistance in bus bar	-
10	valve	AUX LIQ NA	1	N	bellows failure	required new restoration procedure
11	mech. pump	PRIM RX HT	1	N	shield plug leak	redesign to make fault tolerant
12	control rod drive	PLNT CONT	3	Y	drive binds (bent)	develop special tools for remote work in sodium
13	valve	CONT ISOL	6	Y	seat failure, normal wear	detected during annual inspection
14	EM pump	IMPUR MON	3	N	bus bar weld broke inside pump	long time to drain NA from pipes prior to welding
15	rupture disk	SEC RX HT	1	Y	cracked	formulate new preventive maintenance procedure
16	mech. pump	PRIM RX HT	5	Y	shaft binds	new procedure to annually torque shaft
17	valve	IMPUR MON	1	Y	bellows failure	during repair, freeze seal break, fire: revise procedure
18	plug meter	IMPUR MON	1	N	metal filter cracked	caused by failure to follow procedure
19	rupture disk	SEC RX HT	1	Y	leak	new procedure to drain sec. Na system
20	EM pump	AUX LIQ NA	1	N	cooling water blockage	develop new cleaning methods

Table 3. FFTF Maintainability Critical Items

Rank	Component	System	No. Events	Unit Loss	Event	Maintenance Significanc
1	mech pump	PRIM RX HT	1	Y	seal leak Na on shaft	new tests to check shaft clearances
2	EM pump	AUX LIQ NA	1	N	sodium leak	new early detection methods
3	control rod drive	RX SHUTDN	1	N	sticky actuating shaft	very inaccessible
4	mech pump	PRIM RX HT	2	Y	burned brushes	cumbersome procedure for obtaining spares
5	"	"	4	Y	loss speed control: reostat signal	revise PM procedure
6	"	"	1	Y	brushes arc	cumbersome procedure for obtaining spares
7	gas mover	INERT GAS	6	N	lube oil leaks: diaphragm	inaccessible: environmental constraints
8	"	"	2	N	replace blower motor	redesign filter removal mechanism
9	"	"	2	N	remove filter	redesign blower for loss maintenance
10	mech pump	SEC RX HT	1	N	oil seal leakage: Na pump	seal inaccessible
11	penetration	CONTAIN	1	N	airlock seal leakage	redesign alignment device
12	valve	AUX LIQ NA	1	N	Na drain valve leak	-
13	valve	IMPUR MON	1	N	valve operator will not move	inaccessible: environmental constraints
14	NN sensor	RX INST	1	N	detector alarm low: elect. conn.	long retest time
15	NN sensor	H T INST	1	N	temp. alarm indicator oscillates	long diagnostic, retest times
16	NN sensor	GAS INST	1	N	flow pegs high: replace sensor	inaccessible: required scafolding
17	gas mover	INERT GAS	1	N	low lube oil press: diaphragm	inaccessible
18	mech pump	PRIM RX HT	2	N	bearing: change lube design	very long wait for replacement parts
19	NN sensor	INERT GAS	1	N	hygrometer malfunction	excessive maintainance: change component type
20	gas mover	INERT GAS	1	N	compressor oil leak: rotate diaphragm	procedures not followed

Table 4. JOYO Maintainability Critical Items

Rank	Component	System	No. Events	Unit Loss	Event	Maintenance Significance
1	detector	FLUX MON	1	N	wide fluctuations in readings, replace	spare needed, add item to inspection
2	mech pump	SEC RX HT	2	N	replace leaky bearing in electric motor	review greasing method
3	mech pump	SEC RX HT	2	Y	replace insulation in electric motor	attention to environment, install space heater
4	NN sensor	SEC RX HT	2	N	mech. damage to wires by cover plate	spare needed, review installation method
5	control rod drive	REACTOR	2	Y	malfunction limit position indicator	review maintenance procedure
6	valve	AUX LIQ NA	2	N	valve stem overtravel, twists bellows	modify valve stem
7	NN sensor	AUX COOL	1	N	mech. damage to wires by cover plate	review installation method
8	EM pump	AUX LIQ NA	3	Y	failed to start on emergency power	change start sequence
9	mech pump	LUBE OIL	1	N	oil leak through mech. seal	add to prevent maintenance (PM)
10	mech cntrl	SEC RX HT	1	Y	vane blade stuck due to rust	inappropriate salty environment; change bearing material
11	NN sensor	SEC RX HT	10	N	Na leak detect. burned out	review maintenance interval
12	valve	INERT GAS	1	N	would not close, Na unseat	review PM for vapor trap
13	motor	AUX COOL	1	N	beat shaft, broken drive on damper	no spare parts; review op. procedure
14	mech pump	SEC RX HT	2	Y	unusual wear on brushes in electric motor	modify for easier monitoring; skilled craftmen needed
15	mech cntrl	SEC RX HT	1	Y	HEX vane opens 5% without cause	review maintenance procedure
16	mech pump	LUBE OIL	1	N	noisy bearings, replace	review maintenance interval
17	gas mover	AUX LIQ NA	1	N	fan shaft bent	add to PM
18	mech pump	PRIM RX HT	1	Y	seal oil leak	modify oil seal
19	mech cntrl	SEC RX HT	1	Y	vane failed to close due to rust	review maintenance items
20	cntrl rod drive	REACTOR	1	Y	braking pin dislocated	review spare parts inventory

Table 5. Percent of Restoration Time for 20 Highest Ranked Components*

Component	EBR-II	FFTF	JOYO
Mech. pumps	21%	58%	34%
Detectors			20
NN sensors		6	16
Piping	11		
EM pumps	14	8	
Valves			9
Control rods	6	7	8
Mech. control			6
Gas mover		11	
Cold trap	6		
Other	-	-	-

*Only components which rank >5% are compared.

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AN EXAMINATION OF MAINTENANCE ACTIVITIES IN LIQUID METAL REACTOR FACILITIES: AN ANALYSIS BY THE CENTRALIZED RELIABILITY DATA ORGANIZATION (CREDO)

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CREDO

OBJECTIVE

Develop and characterize the maintenance critical items For EBR-II, FFTF, and JOYO liquid metal reactors.

Flagging critical items will enable the focusing of limited resources to resolve problem areas.

CREDO

DEFINITION

A maintenance critical items list is a prioritized list or ranking of those events whose repair contribute to low system maintainability.

CREDO

SCOPE

Critical items for restoration times alone, for EBR-II, FFTF, and EFR reactors.

Only for those components contained in the CREDO data base.

CREDO

COMPONENTS IN CREDO ARE THOSE WHICH:

a) are liquid metal specific

b) are exposed to or associated directly with a liquid metal environment

c) are not tracked by other nuclear data bases

d) could have adverse impact on operations upon failure

CREDO

CREDO Component List

- ANNUNCIATOR MODULES
- BATTERIES
- CIRCUIT BREAKERS AND INTERRUPTERS
- COLD TRAPS AND VAPOR TRAPS
- CONTRACTORS AND STARTERS
- CONTROL ROD DRIVE MECHANISMS
- DEMINERALIZERS
- ELECTRICAL BUSES
- ELECTRICAL CONDUCTORS
- ELECTRIC AND ELECTRICAL CONNECTORS
- ELECTRIC HEATERS
- ELECTROMAGNETIC PUMPS
- FILTER/STRAINERS
- FUSES
- GAS DRYERS
- GAS MOVERS
- GENERATORS
- HEAT EXCHANGERS
- INDICATORS
- INSTRUMENT CONTROLLERS
- INTERNAL COMBUSTION ENGINES
- LIQUID RHEOSTAT
- LOGIC GATES
- MECHANICAL CONTROL DEVICES
- MECHANICAL PUMPS
- MOTORS
- NONNUCLEAR SENSORS
- NUCLEAR DETECTOR
- PENETRATIONS
- PIPE AND FITTINGS
- PLUGGING METERS
- POWER SUPPLIES
- PRSSURE VESSELS AND TANKS
- REACTOR CONTROL RODS
- RECOMBINERS
- RECORDERS
- RELAYS
- RUPTURE DEVICES
- SIGNAL MODIFIERS
- SIGNAL TRANSMITTERS
- SUPPORT AND SHOCK DEVICES
- SWITCHES
- TRANSFORMERS
- TURBINES
- VALVES

CREDO presently:

- tracks 21,000 equipment items
- recorded > 1,300 events
- experience > 1.2 billion component operating hours

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Importance function (I) used to prepare maintenance critical items lists

$$I_i \equiv \frac{\text{mean time repair for item } i}{\text{mean time repair for the system}}$$

$$I_i = \frac{r_i \sum_{i-1}^{N} \lambda_i}{\sum_{i-1}^{N} \lambda_i r_i}$$

where

- r_i – the mean time to repair for item i
- λ_i – the event (failure) rate for item i
- I – importance function
- N – the number of items in the system
- i – the item of interest

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EBR-II Maintainability Critical Items

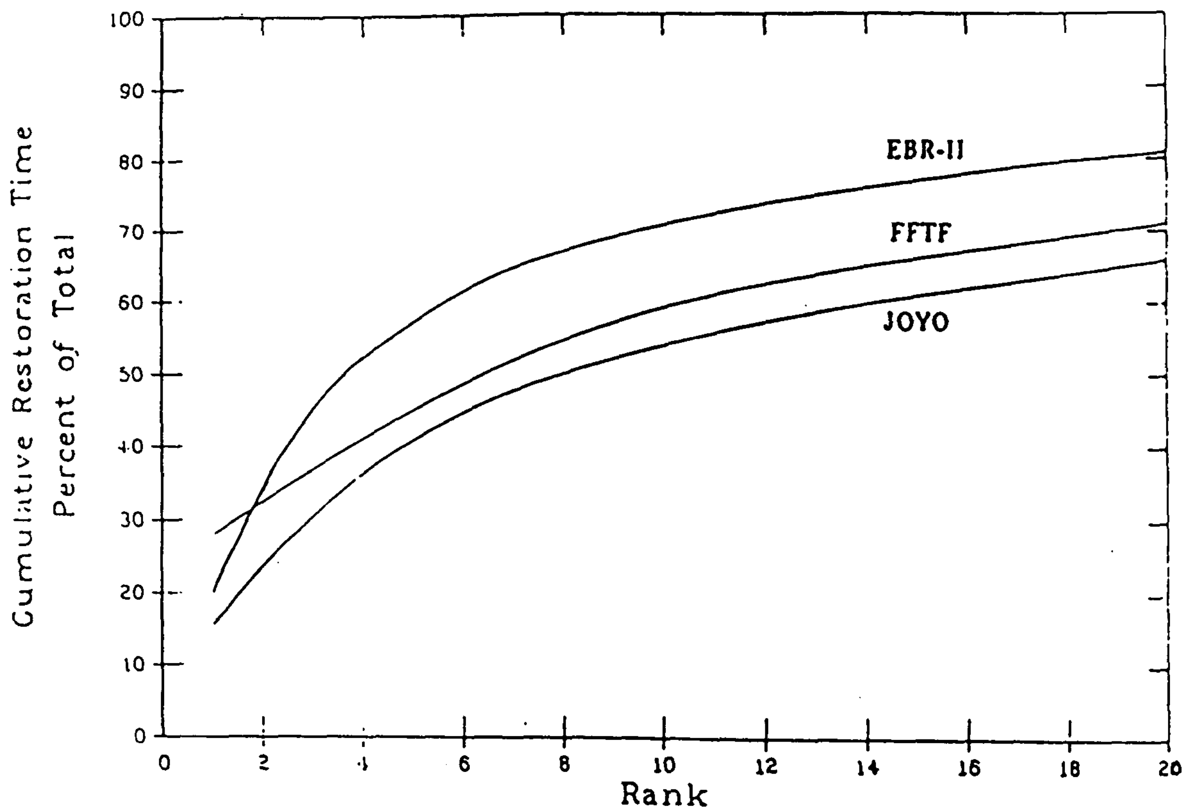
Rank	Component	System	No. Events	Unit Loss	Event	Maintenance Significance
1	mech. pumps	PRIM RX HT	2	Y	shaft found bowed	initial reactor testing
2	piping	SEC RX HT	1	N	broke clamp in fill tube of int. heat exchanger	develop remote TV inspection
3	EM pumps	SEC RX HT	1	Y	cracks in duct	develop sawing, welding technique
4	cold traps	AUX LIQ NA	7	N	traps reach saturation	change design, increase replacement interval
5	control rod drive	PLNT CONT	13	Y	sense rod and jaw bellows failure	install new remote handling container
6	bus bar	PRIM RX HT	1	Y	bus bar eroded	designed technique to weld SS to copper
7	electric heaters	P A EQ HEAT	6	N	burned out heating element	original design did not allow for element replacement
8	filter	GAS COOL	2	N	molecular seive plugged	sleeve redesigned with flange to facilitate maintenance
9	EM pump	AUX LIQ NA	1	N	high resistance in bus bar	-
10	valve	AUX LIQ NA	1	N	bellows failure	required new restoration procedure
11	mech. pump	PRIM RX HT	1	N	shield plug leak	redesign to make fault tolerant
12	control rod drive	PLNT CONT	3	Y	drive binds (bent)	develop special tools for remote work in sodium
13	valve	CONT ISOL	6	Y	seat failure, normal wear	detected during annual inspection
14	EM pump	IMPUR MON	3	N	bus bar weld broke inside pump	long time to drain NA from pipes prior to welding
15	rupture disk	SEC RX HT	1	Y	cracked	formulate new preventive maintenance procedure
16	mech. pump	PRIM RX HT	5	Y	shaft binds	new procedure to annually torque shaft
17	valve	IMPUR MON	1	Y	bellows failure	during repair, freeze seal break, fire: revise procedure
18	plug meter	IMPUR MON	1	N	metal filter cracked	caused by failure to follow procedure
19	rupture disk	SEC RX HT	1	Y	leak	new procedure to drain sec. Na system
20	EM pump	AUX LIQ NA	1	N	cooling water blockage	develop new cleaning methods

FFTF Maintainability Critical Items

Rank	Component	System	No. Events	Unit Loss	Event	Maintenance Significance
1	mech pump	PRIM RX HT	1	Y	seal leak Na on shaft	new tests to check shaft clearances
2	EM pump	AUX LIQ NA	1	N	sodium leak	new early detection methods
3	control rod drive	RX SHUTDN	1	N	sticky actuating shaft	very inaccessible
4	mech pump	PRIM RX HT	2	Y	burned brushes	cumbersome procedure for obtaining spares
5	"	"	4	Y	loss speed control: reostat signal	revise PM procedure
6	"	"	1	Y	brushes arc	cumbersome procedure for obtaining spares
7	gas mover	INERT GAS	6	N	lube oil leaks: diaphragm	inaccessible: environmental constraints
8	"	"	2	N	replace blower motor	redesign filter removal mechanism
9	"	"	2	N	remove filter	redesign blower for loss maintenance
10	mech pump	SEC RX HT	1	N	oil seal leakage: Na pump	seal inaccessible
11	penetration	CONTAIN	1	N	airlock seal leakage	redesign alignment device
12	valve	AUX LIQ NA	1	N	Na drain valve leak	-
13	valve	IMPUR MON	1	N	valve operator will not move	inaccessible: environmental constraints
14	NN sensor	RX INST	1	N	detector alarm low: elect. conn.	long retest time
15	NN sensor	H T INST	1	N	temp. alarm indicator oscillates	long diagnostic, retest times
16	NN sensor	GAS INST	1	N	flow pegs high: replace sensor	inaccessible: required scafolding
17	gas mover	INERT GAS	1	N	low lube oil press: diaphragm	inaccessible
18	mech pump	PRIM RX HT	2	N	bearing: change lube design	very long wait for replacement parts
19	NN sensor	INERT GAS	1	N	hygrometer malfunction	excessive maintainance: change component type
20	gas mover	INERT GAS	1	N	compressor oil leak: rotate diaphragm	procedures not followed

JOYO Maintainability Critical Items

Rank	Component	System	No. Events	Unit Loss	Event	Maintenance Significance
1	detector	FLUX MON	1	N	wide fluctuations in readings, replace	spare needed, add item to inspection
2	mech pump	SEC RX HT	2	N	replace leaky bearing in electric motor	review greasing method
3	mech pump	SEC RX HT	2	Y	replace insulation in electric motor	attention to environment, install space heater
4	NN sensor	SEC RX HT	2	N	mech. damage to wires by cover plate	spare needed, review installation method
5	control rod drive	REACTOR	2	Y	malfunction limit position indicator	review mainte nance procedure
6	valve	AUX LIQ NA	2	N	valve stem overtravel, twists bellows	modify valve stem
7	NN sensor	AUX COOL	1	N	mech. damage to wires by cover plate	review installation method
8	EM pump	AUX LIQ NA	3	Y	failed to start on emergency power	change start sequence
9	mech pump	LUBE OIL	1	N	oil leak through mech. seal	add to prevent maintenance (PM)
10	mech cntrl	SEC RX HT	1	Y	vane blade stuck due to rust	inappropriate salty environment; change bearing material
11	NN sensor	SEC RX HT	10	N	Na leak detect. burned out	review maintenance interval
12	valve	INERT GAS	1	N	would not close, Na unseat	review PM for vapor trap
13	motor	AUX COOL	1	N	beat shaft, broken drive on damper	no spare parts; review op. procedure
14	mech pump	SEC RX HT	2	Y	unusual wear on brushes in electric motor	modify for easier monitoring; skilled craftmen needed
15	mech cntrl	SEC RX HT	1	Y	HEX vane opens 5% without cause	review maintenance procedure
16	mech pump	LUBE OIL	1	N	noisy bearings, replace	review maintenance interval
17	gas mover	AUX LIQ NA	1	N	fan shaft bent	add to PM
18	mech pump	PRIM RX HT	1	Y	seal oil leak	modify oil seal
19	mech cntrl	SEC RX HT	1	Y	vane failed to close due to rust	review maintenance items
20	cntrl rod drive	REACTOR	1	Y	braking pin dislocated	review spare parts inventory

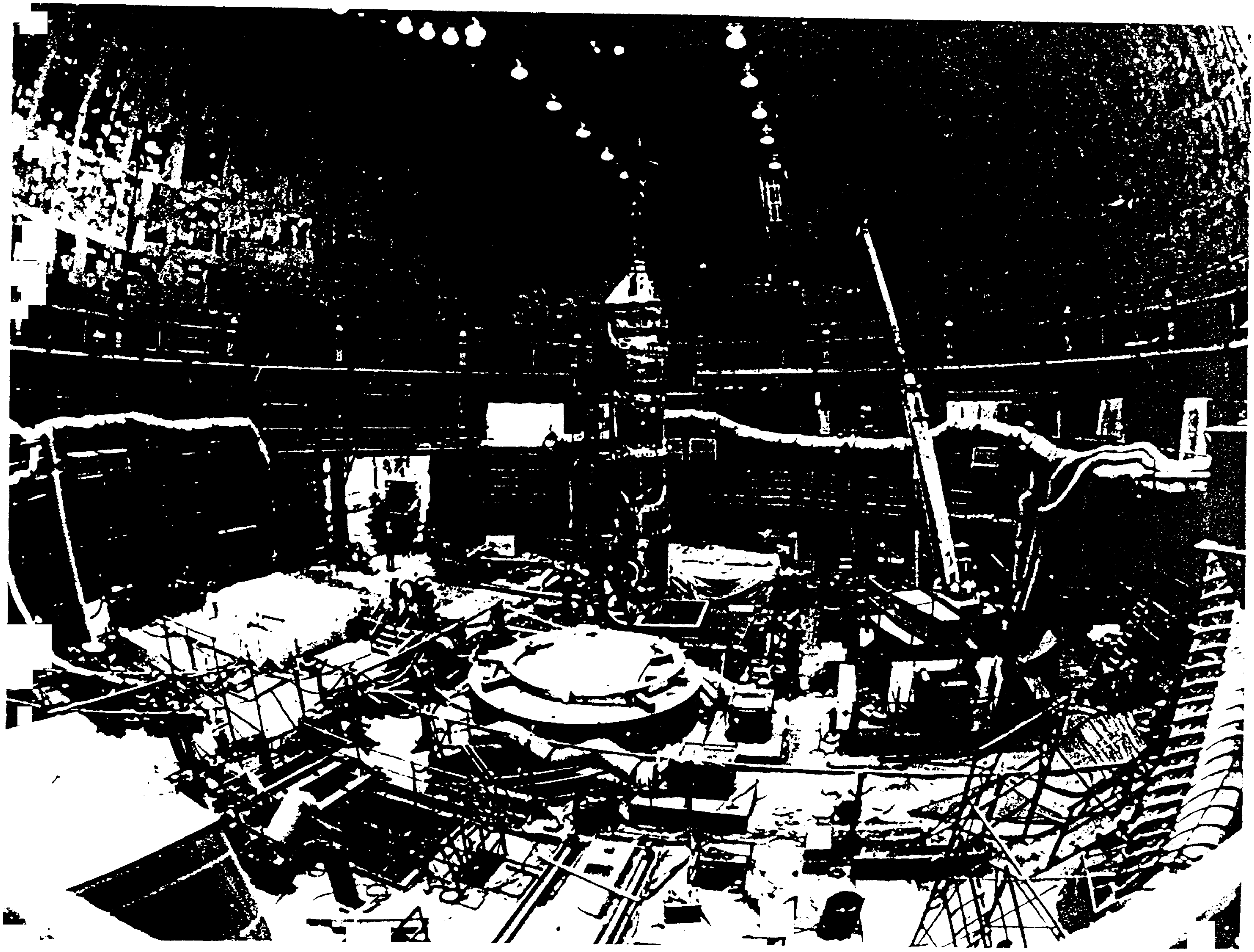


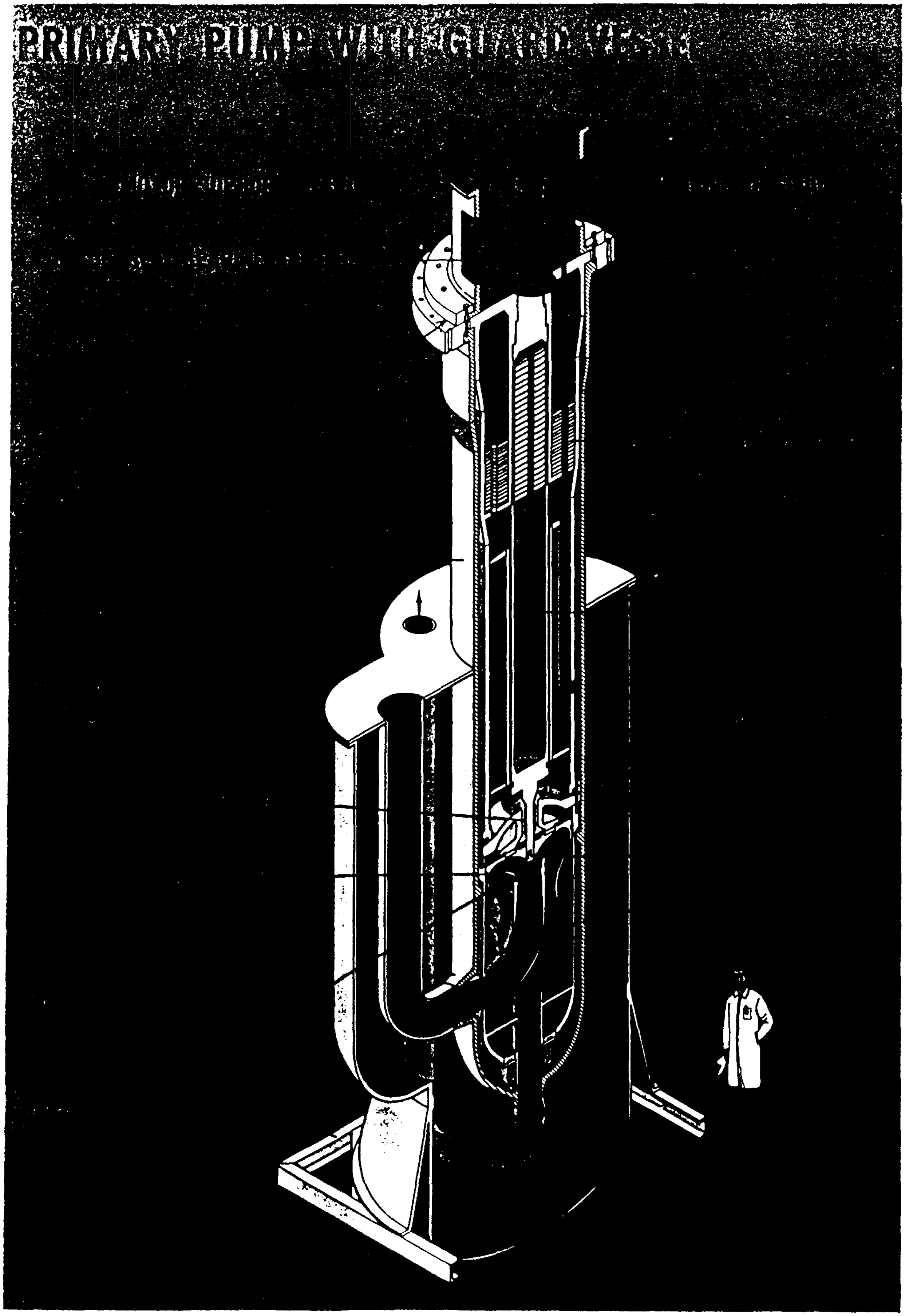
Cumulative restoration time as a function of maintenance critical item rank .

Table 5. Percent of Restoration Time for 20 Highest Ranked Components*

Component	EBR-II	FFTF	JOYO
Mech. pumps	21%	58%	34%
Detectors			20
NN sensors		6	16
Piping	11		
EM pumps	14	8	
Valves			9
Control rods	6	7	8
Mech. control			6
Gas mover		11	
Cold trap	6		
Other	-	-	-

*Only components which rank >5% are compared.





J. L. S

CAUSES FOR LONG DOWNTIME

CAUSE	RESOLUTION
1. INACCESSIBILITY, AWKWARDNESS (for mechanical items)	DESIGN
2. ENVIRONMENTAL CONSTRAINTS - SODIUM DRAINING AND CLEANUP - WAITING FOR RADIOACTIVE DECAY	DESIGN
3. INADEQUATE DETECTION OF DETERIORATING CONDITIONS	OPERATIONS
4. SLOW DIAGNOSIS (for electrical, electronic items)	OPERATIONS
5. INAPPROPRIATE SPARE PART INVENTORY	OPERATIONS
6. LONG RETEST	OPERATIONS
7. ADMINISTRATIVE OVERHEAD	OPERATIONS

CONCLUSION

1. A very few events dominate the length of downtime for each LMR site.

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2. There does not appear to be any time dependence to the length of downtime.

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3. Mechanical coolant pumps are the primary contributor to restoration time. The dominate mode of failure is different for each site.

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4. Designing for maintenance during early facility design phases is essential to alleviate problems concerning inaccessibility and environmental constraints.

   Better non-intrusive surveillance techniques would enable earlier detection, better diagnosis and faster retesting.

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5. Most effort to improve availability has has been directed at improving equipment reliability. Greater emphasis should be placed on means of reducing downtime, once an event has occurred.

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