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GENERIC COMPONENT FAILURE DATA BASE FOR
LIGHT WATER AND LIQUID SODIUM REACTOR PRAs

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FOR LIGHT WATER AND LIQUID SODIUM REACTOR PRAs

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February 1990

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ABSTRACT

A comprehensive generic component failure data base has been developed for light water and liquid sodium reactor probabilistic risk assessments (PRAs). The Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR) and the Centralized Reliability Data Organization (CREDO) data bases were used to generate component failure rates. Using this approach, most of the failure rates are based on actual plant data rather than existing estimates.

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GENERIC COMPONENT FAILURE DATA BASE FOR LIGHT WATER AND LIQUID SODIUM REACTOR PRAs

1. INTRODUCTION

A comprehensive generic component failure data base has been developed for light water and liquid sodium reactor probabilistic risk assessments (PRAs). A major goal was to base the component failure rates as much as possible on available plant data rather than estimates or data from other types of facilities. The Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR)¹ and Centralized Reliability Data Organization (CREDO)² data programs were used to achieve this goal. For component failure modes not covered by these sources, other standard sources such as IEEE Std-500³, Seabrook PRA⁴, WASH-1400⁵, or GEFRR-00554⁶ were used. The resultant data base is organized into four categories: mechanical components (water or steam working fluid), mechanical components (sodium working fluid), mechanical components (air or gas working fluid), and electrical components. The results are presented in Tables 1 through 4. Also shown in these tables are comparisons with other data sources.

2. COMPONENTS AND FAILURE MODES

A comprehensive list of mechanical and electrical components and failure modes was generated by reviewing other data bases and various PRAs. For electrical components, the component list was heavily influenced by the contents of IEEE Std-500. The resulting list of components is presented in Tables 1 through 4. For valves listed in these tables, the component boundary is defined to include the valve body, valve operator, and limit or torque switches mounted on the valve. Other local instrumentation and control circuitry is not considered to be part of the valve component boundary. Support systems such as ac or dc power, air, or hydraulic are not included. In addition, for pneumatic valves, the associated solenoid valve which controls the air supply is not included. For pumps, the boundary is similar. The pump body, driver, and any local mechanical control are included. Instrumentation and control circuitry is not included.

It should be noted that the many data sources contained in NUCLARR, CREDO, and others used in this study are not always consistent with the component boundaries listed above. For example, the NUCLARR data base has a field in each data report which can be used to indicate whether instrumentation and control circuitry has been included with the pump or valve. However, it is not always clear for the PRA data sources whether such failures have been included with the valve or pump data. Also, the CREDO data collection effort has not always been consistent in this area. The component boundaries outlined above are presented to ensure consistent use of the data base. The precision of the boundary definitions is not meant to imply the same precision in the actual data collection for the various sources utilized.

For valves, the following typical failure modes generally were used:

Fail to open

Fail to close

Spurious operation (spurious opening or closing of the valve caused by a fault in the valve remote operator)

Plug (caused by the valve disk or foreign material)

Internal leakage (minor)

Internal rupture (large or catastrophic)

External leakage (minor)

External rupture (large or catastrophic).

For manual valves, no spurious failure mode is listed because there is no remote operator. Also, failure to open and failure to close were combined if the failure rates are similar or if the data do not distinguish the two.

For pumps, the following typical failure modes were generally used:

Fail to start

Fail to run

External leakage (minor)

External rupture (large or catastrophic).

Other components usually have fewer failure modes, because either the data do not distinguish the modes or there is only one mode of interest, such as external leakage.

The final list of components and failure modes is presented in Tables 1 through 4.

3. DATA SOURCES

As mentioned in the introduction, a major goal in the generic data base development was to base failure rates on actual plant data. Also, the data had to be accessible for review. To this end, the NUCLARR and CREDO data bases were chosen as the prime sources. Each is described below.

The NUCLARR data collection and software development is an ongoing program supported by the United States Nuclear Regulatory Commission (NRC). The program includes two separate focuses: human error estimates and models, and component failure data. Only the component failure data were used in this application. As part of this effort, the number of data entries was increased substantially. As a result, NUCLARR (as of February 1990) now has 19 PRA plant-specific data sources. These sources contain plant-specific component failure data collected as part of the PRAs or reliability studies performed on those plants. It is believed that these data are the most accurate available both in terms of comprehensive searches for and screening of component failures and in terms of detailed accounting of demands or hours.

NUCLARR also contains data from various Licensee Event Report (LER) surveys⁷⁻¹⁰ and In-Plant Reliability Data (IPRD) reports¹¹⁻¹³. These data sources are also based on plant data. However, both types of sources estimated the number of component demands (usually one demand per month), and LERs do not always cover all component failures. Therefore, the data from these sources are not considered to be as accurate as the PRA plant-specific data sources.

Finally, NUCLARR also contains component failure data from IEEE Std-500, NPRD-3¹⁴, and WASH-1400.

When using the NUCLARR software, all sources were identified for a given component and failure mode. After the selection of sources, sophisticated aggregation routines (see the NUCLARR documentation for an explanation of the routines) combined the source data to obtain a failure rate distribution. In order to use the best data available for the generic data base, the NUCLARR

sources were divided into three groups: category 1 (19 PRA data sources), category 2 (LER and IPRD data), and category 3 (IEEE Std-500, NPRD-3, and WASH-1400). These categories and sources are presented in Table 5. For each component failure mode, the NUCLARR software was used to generate failure rate distributions from each of the three categories (if data existed). Results of this effort are presented in Tables 6 and 7. A review of Tables 6 and 7 indicates that many of the component failure modes have a failure rate distribution derived from the category 1 sources. This comprehensive coverage by category 1 data is the strength of the NUCLARR data base.

For mechanical components processing liquid sodium, the CREDO data base was used. The CREDO data base includes data from liquid metal reactors and research facilities in the United States and Japan. The CREDO program is ongoing and was started in 1977. Support comes from the United States Department of Energy and, recently, from the Japanese government. Data searches were performed on CREDO as it existed in February 1990, utilizing all data sources. However, only sodium and sodium-potassium working fluids were considered. Also, in order to obtain data categorized by the typical failure modes discussed previously, the numerous CREDO failure modes had to be assigned to the modes desired. A summary of the assignments is presented in Table 8. The CREDO failure records were reviewed in detail. In some cases the assigned failure modes were changed. Also, many of the events were not considered to be failures in the PRA sense and were eliminated. Results of the CREDO data searches are summarized in Table 9. Details of the failure record review are presented in the appendix. In order to be consistent with the aggregation routines used in NUCLARR, the mean values were calculated based on a Bayesian update of a noninformative prior.

The equations for the mean are the following¹⁵:

mean = $(2n + 1) / (2T)$ time-related failure
and

mean = $(2n + 1) / (2D + 2)$ demand-related failure

where

n = number of failures

T = time period (h)

D = number of demands.

4. RECOMMENDED FAILURE RATES

Based mainly on the NUCLARR and CREDO results in Tables 6,7, and 9, recommended failure rates were generated. For mechanical components (water, steam, air, or gas working fluids) and electrical components, the recommended failure rates were obtained from one of the following (in order of preference):

NUCLARR category 1

NUCLARR category 2

NUCLARR category 3

Seabrook PRA

IEEE Std-500

Brookhaven

WASH-1400.

For mechanical components (sodium working fluid), recommended values came from (in order of preference):

CREDO

GEFR-00554.

In all cases, the recommended mean failure rates were rounded off to 1.0, 3.0, or 5.0 (times the appropriate power of 10). (For a generic data base, such rounding off is believed to be appropriate.) Also, error factors (95th percentile/median) of 3, 5, 10, or 30 were chosen, based partly on the error factors from the various sources and partly on judgement. (It is believed

that the sophisticated data aggregation routines in NUCLARR have the potential for resulting in realistic error factors. However, for the routines to work well, plant-specific data should be reported on an individual component basis. Unfortunately, such is often not the case even for the 19 PRA sources grouped as category 1 sources. Whenever component data are lumped together, information on component variability is lost. This often results in a smaller error factor being calculated in NUCLARR compared with a case where all components are reported separately. Therefore, the NUCLARR error factors, where available, were used only for guidance in the choice of 3, 5, 10, or 30.) Only for water or steam pipe leakages was an error factor of 30 used. This is because the recommended values came directly from WASH-1400, which indicated error factors of 30. In all other cases, the upper bound error factor was chosen to be 10.

Recommended generic failure rate distributions are presented in Tables 1 through 4. The results are characterized by a mean and error factor. A lognormal distribution is assumed for all of the component failure modes. Also shown in the tables are comparisons with a representative sample of other sources. For mechanical components (water, steam, air, or gas working fluids) and electrical components, the comparison sources are the Accident Sequence Evaluation Program (ASEP) generic data base¹⁶, the Brookhaven National Laboratory PRA procedures guide¹⁷, IEEE Std-500, Seabrook PRA, and WASH-1400. For mechanical components (sodium working fluid), the sources are the Liquid Metal Engineering Center (LMEC)¹⁸, a paper summarizing French operating experience¹⁹, a sodium piping survey²⁰, the most recent Clinch River Breeder Reactor Plant PRA²¹, and GEF-00554. It is believed that the recommended failure rates may be more representative of actual plant component behavior than those values quoted in the other sources. This is because of the heavy reliance on actual plant data contained in NUCLARR and CREDO. However, for component failure modes with no actual failures, the recommended failure rates are most likely conservative. (Such cases are indicated in the tables.) In such cases the data base user may want to calculate a more realistic failure rate distribution by using some alternative methodology.

5. REFERENCES

1. D. I. Gertman et al., Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR), NUREG/CR-4639, June 1989.
2. J. J. Manning et al., 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, ORNL/TM-9892, November 1986.
3. IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear-Power Generating Stations, IEEE Std. 500-1984, 1983.
4. Public Service Company of New Hampshire, Seabrook Station Probabilistic Safety Assessment, December 1983.
5. Reactor Safety Study: An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants, WASH-1400 (NUREG 75/014), October 1975.
6. O. Gokcek and R. J. Nicholls, Reliability Data for the CRBRP Shutdown Heat Removal System, CRBRP-GEFR-00554 (draft), Revision 2, January 1983.
7. M. Trojovsky, Data Summaries of Licensee Event Reports of Pumps at U. S. Commercial Nuclear Power Plants, NUREG/CR-1205, Revision 1, January 1982.
8. C. F. Miller et al., Data Summaries of Licensee Event Reports of Valves at U. S. Commercial Nuclear Power Plants, NUREG/CR1363, Revision 1, October 1982.
9. C. F. Miller et al., Data Summaries of Licensee Event Reports of Selected Instrumentation and Control Components at U. S. Commercial Nuclear Power Plants, NUREG/CR-1740, May 1981.
10. M. Trojovsky and S. Brown, Data Summaries of Licensee Event Reports of Inverters at U. S. Commercial Nuclear Power Plants, NUREG/CR-3867, August 1984.
11. J. P. Drago et al., The In-Plant Reliability Data Base for Nuclear Plant Components: Interim Data Report - The Pump Component, NUREG/CR-2886, December 1982.
12. R. J. Borkowski et al., The In-Plant Reliability Data Base for Nuclear Plant Components: Interim Data Report - The Valve Component, NUREG/CR-3154, December 1983.
13. W. K. Kahl and R. J. Borkowski, The In-Plant Reliability Data Base for Nuclear Plant Components: Interim Report - Diesel Generators, Batteries, Chargers, and Inverters, NUREG/CR-3831, January 1985.

14. M. J. Rossi, Nonelectronic Parts Reliability Data, NPRD-3, 1985.
15. PRA Procedures Guide, NUREG/CR-2300, January 1983.
16. M. T. Drouin, F. T. Harper, and A. L. Camp, Analysis of Core Damage Frequency from Internal Events: Methodology Guidelines, NUREG/CR-4550, Volume 1, September 1987.
17. R. A. Bari et al., Probabilistic Safety Analysis Procedures Guide, NUREG/CR-2815, August 1985.
18. Liquid Metal Engineering Center, Failure Data Handbook, LMEC-Memo-69-7, June 1970.
19. Atomics International, Sodium Piping Survey to July 1977, AI-DOE-13225, February 1978.
20. J. Boisseau et al., "Failure Rate Evaluation for Different Components Operating in Sodium, Based on Operating Experience of the Rapsodie and the Phenix Reactors and the Test Loops," Proceedings of the L.M.F.B.R. Safety Topical Meeting, Volume II, Lyon-Ecully, France, July 1982, pp. 677-686.
21. Technology for Energy Corporation, Clinch River Breeder Reactor Plant Probabilistic Risk Assessment, CRBRP-4, 1984.

Table 1. Mechanical component (water or steam working fluid) recommended failure rates

MECHANICAL COMPONENT (WATER OR STEAM WORKING FLUID) FAILURE RATE COMPARISON																			
SOURCES																			
		RECOMMENDED (A)			ASEP			BROOKHAVEN (IREP/NREP) (B)			IEEE STD 500 (C)			SEABROOK PRA (D)			WASH-1400		
COMPONENTS	FAILURE MODES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES
VALVES																			
MANUAL	FAIL TO OPEN/CLOSE PLUG	5 0E-04 /D	10	N1	-			2 0E-07 /H	3 5		-			-			-		
	INTERNAL LEAKAGE	3 0E-09 /H	10	N2	4 0E-05 /D	3		-			-			4 2E-08 /H	9 2	1	1 2E-04 /D	3	
	INTERNAL RUPTURE	-			-			-			-			-			-		
	EXTERNAL LEAKAGE	5 0E-08 /H	10	S	-			-			-			4 2E-08 /H	9 2	1	-		
	EXTERNAL RUPTURE	3 0E-08 /H	10	N2	-			-			-			-			2 7E-08 /H (E) (F)	10	
		-			-			-			-			-			-		
MOTOR-OPERATED	FAIL TO OPEN/CLOSE PLUG	3 0E-03 /D	5	N1	3 0E-03 /D	3		1 0E-05 /H	15 8		6 0E-03 /D		1	4 3E-03 /D	3 7		1 2E-03 /D	3	
	INTERNAL LEAKAGE	5 0E-08 /H	10	N1	-			2 0E-07 /H (E) (F)	3 5		-			9 3E-08 /H	4 6	1	3 8E-07 /H (E) (F)	3	1
	INTERNAL RUPTURE	5 0E-09 /H	10	N2	4 0E-05 /D	3		-			3 0E-08 /H		1	-		-	-		
	EXTERNAL LEAKAGE	-			-			-			-			-			-		
	EXTERNAL RUPTURE	1 0E-07 /H	10	B	-			1 0E-07 /H	83 7	1	-			-			2 7E-08 /H (E) (F)	10	
		1 0E-07 /H	10	N2	-			-			1 0E-07 /H		1	-			-	-	
PNEUMATIC	FAIL TO OPEN/CLOSE PLUG	1 0E-03 /D	10	N1	1 0E-03 /D	3		1 0E-05 /H	15 8		2 0E-03 /D		2	1 5E-03 /D	3 1		3 8E-04 /D	3	
	INTERNAL LEAKAGE	3 0E-06 /H	10	N1	-			-			-			2 7E-07 /H	7 3	1	3 8E-07 /H (E) (F)	3	1
	INTERNAL RUPTURE	3 0E-08 /H	10	N2	4 0E-05 /D	3		-			-			-			-		
	EXTERNAL LEAKAGE	1 0E-06 /H	10	N1	-			-			-			-			-		
	EXTERNAL RUPTURE	-			-			-			-			-			-		
		1 0E-07 /H	10	N2	-			-			1 0E-07 /H		2	-			2 7E-08 /H (E) (F)	10	
SOLENOID	FAIL TO OPEN/CLOSE PLUG	5 0E-04 /D	10	N1	1 0E-03 /D	3		2 0E-06 /H	3 5		-			2 4E-03 /D	9 5		1 2E-03 /D	3	
	INTERNAL LEAKAGE	5 0E-07 /H	10	N1 0	-			-			-			1 3E-06 /H	8 3	1	1 2E-04 /D (E) (F)	3	1
	INTERNAL RUPTURE	3 0E-08 /H	10	1	4 0E-05 /D	3		-			-			-			-		
	EXTERNAL LEAKAGE	1 0E-06 /H	10	1	-			-			-			-			-		
	EXTERNAL RUPTURE	-			-			-			-			-			-		
		1 0E-07 /H	10	1	-			-			-			-			2 7E-08 /H (E) (F)	10	
VACUUM-BREAKER	FAILS TO OPEN	1 0E-02 /D	10	N1	-			6 0E-08 /H	4 5		-			-			3 8E-05 /D	3	2
CHECK	FAIL TO OPEN PLUG	5 0E-05 /D	5	N1	1 0E-04 /D	3		2 0E-07 /H	3 5		6 0E-05 /D		3	2 7E-04 /D	4 4		1 2E-04 /D	3	
	FAIL TO CLOSE	5 0E-09 /H	10	N2	-			-			-			1 0E-08 /H	3		-		
	INTERNAL LEAKAGE	1 0E-03 /D	5	N1	1 0E-03 /D	3		2 0E-06 /H	4 1		-			2 7E-04 /D	4 4		-		
	INTERNAL RUPTURE	3 0E-06 /H	10	N1	-			3 0E-06 /H	18 3	2	5 0E-07 /H		3	-	4		3 8E-07 /H	3	
	EXTERNAL LEAKAGE	5 0E-07 /H	10	S	-			1 0E-07 /H	83 7	3	-			5 4E-07 /H			2 73-08 /H (E) (F)	10	
	EXTERNAL RUPTURE	5 0E-08 /H	10	N2	-			-			5 0E-08 /H		3	-			-		
SAFETY	FAIL TO OPEN	3 0E-04 /D	5	S	1 0E-05 /D	3		2 0E-05 /H OR 6 0E-07 /H	5 3 7	4 5	4 0E-03 /D		4	3 3E-04 /D	8 9	2	-		
	PREMATURE OPENING	3 0E-06 /D	10	1	-			-			3 0E-06 /H		4	-			-		
	FAIL TO RECLOSE	3 0E-03 /D	5	S	3 0E-02 /D	10		2 0E-05 /H	5	4 5	-			2 9E-03 /D	3	2	-		
RELIEF	FAIL TO OPEN	3 0E-03 /D	5	N1	1 0E-05 /D	3	1	-			1 0E-02 /D		5	2 4E-05 /D OR 4 3E-03 /D	9 5 3	3	1 2E-05 /D	3	
	PREMATURE OPENING	5 0E-06 /H	10	S	-			-			4 0E-06 /H		5	6 1E-06 /H	3 6		1 2E-05 /H	3	
	FAIL TO RECLOSE	3 0E-03 /D	5	N1	3 0E-02 /D	10	1	-			3 0E-03 /D		5	2 5E-02 /D	3	3	-		

Table 1. (continued)

MECHANICAL COMPONENT (WATER OR STEAM WORKING FLUID) FAILURE RATE COMPARISON

COMPONENTS		SOURCES																	
		RECOMMENDED (A)			ASEP			BROOKHAVEN (IREP/NREP) (B)			IEEE STD 300 (C)			SEABROOK PRA (D)			WASH-1400		
		MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES
ORFICES	PLUG	3 0E-04 /D	3	W	-			6 0E-07 /H	3 7		-			-			3 8E-04 /D	3	
PUMPS	MOTOR-DRIVEN																		
	FAIL TO START	3 0E-03 /D	5	N1	3 0E-03 /D	10		1 0E-05 /H	15 8		-			3 3E-03 /D OR 2 4E-03 /D	6 9 5 1	4 5	1 2E-03 /D	3	3
	FAIL TO RUN	3 0E-05 /H	10	N1	3 0E-05 /H	10		1 0E-04 /H	15 8		-			3 4E-05 /H OR 3 4E-05 /H	5 3 6 2	4 5	8 0E-05 /H (E) OR 2 70E-05 /H (E)	10 10	4
	EXTERNAL LEAKAGE	3 0E-06 /H	10	N2	-			-			-			-			(F)		
	EXTERNAL RUPTURE	-			-			-			-			-			(F)		
	TURBINE-DRIVEN																		
	FAIL TO START	3 0E-02 /D	5	N1	3 0E-02 /D	10		1 0E-04 /H	15 8		-			3 3E-02 /D	3 4		1 2E-03 /D	3	3
	FAIL TO RUN	1 0E-04 /H	10	N1	5 0E-03 /H	10		2 0E-05 /H	3 5		-			1 0E-03 /H	7 1		8 0E-05 /H (E) OR 2 7E-05 /H (E)	10 10	4
	EXTERNAL LEAKAGE	5 0E-07 /H	10	N2	-			-			-			-			(F)		
	EXTERNAL RUPTURE	-			-			-			-			-			(F)		
	DIESEL-DRIVEN																		
	FAIL TO START	1 0E-02 /D	5	N1	1 0E-03 /D	3		1 0E-06 /H	15 8		-			-			-		
	FAIL TO RUN	5 0E-03 /H	10	N1	8 0E-04 /H	10		-			-			-			-		
	EXTERNAL LEAKAGE	3 0E-06 /H	10	N2	-			-			-			-			-		
	EXTERNAL RUPTURE	-			-			-			-			-			-		
HEAT EXCHANGERS	SHELL																		
	EXTERNAL LEAKAGE	3 0E-07 /H	10	N1 0	3 0E-06 /H (E)	10	2	3 0E-06 /H	18 3		-			1 9E-06 /H (E)	3 9	6	-		
	EXTERNAL RUPTURE	-			(F)			-			-			(F)			-		
	TUBE (PER UNIT)																		
	LEAKAGE	1 0E-06 /H	10	N1 0	(F)			3 0E-09 /H	18 3	6	-			(F)			-		
	RUPTURE	-			(F)			-			-			(F)			-		
	PLUG	3 0E-07 /H	10	N1 0	5 7E-06 /H	10		-			-			(F)			-		
VESSELS	TANK																		
	EXTERNAL LEAKAGE	5 0E-07 /H	10	N1 0	-			-			-			-			-		
	EXTERNAL RUPTURE	-			-			-			-			2 7E-08 /H	10		-		
	REACTOR VESSEL																		
	EXTERNAL LEAKAGE	-			-			-			-			-			-		
	EXTERNAL RUPTURE	3 0E-11 /H	10	W	-			-			-			-			3 0E-11 /H	10	5
PIPES	1-3 INCH (PER FOOT)																		
	LEAKAGE	1 0E-08 /H	30	W	-			-			-			-			8 5E-09 /H	30	6
	RUPTURE	5 0E-10 /H	30	W	-			-			-			4 3E-10 /H	30	7	4 3E-10 /H	30	
	PLUG	5 0E-10 /H	30	W	-			-			-			-			4 3E-10 /H	30	
	>3 INCH (PER FOOT)																		
	LEAKAGE	1 0E-09 /H	30	W	-			-			-			-			8 5E-10 /H	30	6
	RUPTURE	5 0E-11 /H	30	W	-			-			-			4 3E-11 /H	30	7	4 3E-11 /H	30	
	PLUG	5 0E-11 /H	30	W	-			-			-			-			4 3E-11 /H	30	

Table 1. (continued)

MECHANICAL COMPONENT (WATER OR STEAM WORKING FLUID) FAILURE RATE COMPARISON

		SOURCES																	
COMPONENTS	FAILURE MODES	RECOMMENDED (A)			ASEP			BROOKHAVEN (IREP/NREP) (B)			IEEE STD 500 (C)			SEABROOK PRA (D)			WASH-1400		
		MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES
GASKETS	EXTERNAL LEAKAGE EXTERNAL RUPTURE	3 0E-05 /H -	30	W	- -			- -			- -			- -			2 6E-05 /H -	30	7
STRAINERS	PLUG FAIL OPEN	5 0E-06 /H -	10	N1	- -			3 0E-05 /H -	18 3		- -			6 2E-06 /H (E) (F)	3 6	8	- -		
GENERATOR																			
DIESEL	FAIL TO START FAIL TO RUN	1 0E-02 /D 5 0E-03 /H	5 10	N1 N1	3 0E-02 /D 2 0E-03 /H	3 10		6 0E-05 /H 3 0E-03 /H	3 7 18 3		1 8E-02 /D 1 7E-04 /H	6 6		2 1E-02 /D 1 7E-02 /H OR 2 5E-03 /H	4 8 9 10		3 8E-02 /D 8 0E-03 /H OR 8 0E-04 /H	3 10 10	8
HYDRO-TURBINE	FAIL TO START FAIL TO RUN	3 0E-03 /D -	5	N1	- -			- -			- -			- -			- -		
MOTOR-DRIVEN	FAIL TO START FAIL TO RUN	- 3 0E-05 /H			- -			- -			- -			- -			- -		
GAS-TURBINE	FAIL TO START FAIL TO RUN	3 0E-02 /D 3 0E-04 /H	5 10	N1 N1	- -			- -			- -			- -			- -		
CONTROL ROD	FAIL TO INSERT	3 0E-05 /D	10	S	-			-			-			3 3E-05 /D	29 4		1 2E-04 /D	3	
CLUTCH	FAIL TO ENGAGE PREMATURE DISENGAGEMENT	3 0E-04 /D -	5	W	- -			- -			- -			- -			3 8E-04 /D -	3	

NOTES

- (A) Recommended value obtained from NUCLARR, if available. If not then IEEE, Seabrook, or WASH-1400 value was used. Mean value was rounded off to 1 0E-1, 3 0E-1, or 5 0E-1. Error factor was estimated and rounded off to 3, 5, 10, 30.
- (B) The error factor was obtained from the square root of maximum value/minimum value.
- (C) Recommended value considered to be a mean because very few sources were used and for these components the values from these sources are considered to be means. Error factor obtained from the square root of high value/low value. For cases with no low value, error factor is high value/recommended value.
- (D) Error factor obtained from 95th value/median.
- (E) This failure rate includes other failure modes.
- (F) Covered by failure rate listed above.

RECOMMENDED

- N1 From NUCLARR category 1 sources
 N2 From NUCLARR category 2 sources
 N3 From NUCLARR category 3 sources
 B From Brookhaven
 S From Seabrook PRA
 W From WASH-1400
 0 Based on no failures
 1 Pneumatic valve value used

ASEP

- 1 Power-operated relief valve (PORV)
 2 Leakage/rupture not specified as shell or tube

Table 1. (continued)

BROOKHAVEN	
1	Catastrophic internal leakage
2	Minor internal leakage
3	Catastrophic internal leakage
4	Primary safety valve
5	Code safety valve
6	Per tube
IEEE	
1	From page 1021
2	From page 1025
3	From page 1066
4	From page 1040
5	From page 1030
6	From page 1211
SEABROOK	
1	Transfers open/closed during operation
2	Primary safety valve
3	Power-operated relief valve (PORV)
4	Standby pump.
5	Normally-operating pump
6	Rupture/excessive leakage during operation
7	Assuming 20 ft per section
8	Fail during operation
9	During first hour of operation
10	After first hour of operation
WASH-1400	
1	Does not include command faults (spurious signals)
2	Value is for failure to operate
3	Type of pump driver not distinguished
4	Type of pump driver not distinguished includes leakage/rupture failures
5	From page V-45
6	Section 6.4 in Appendix III indicates only 5% of leakages are ruptures Therefore the rupture value listed in Table III 4-2 is multiplied by 20 This value assumes 20 ft per section
7	For containment quality gasket during severe post accident conditions
8	First value is for complete plant second is for engine only

Table 2. Mechanical component (sodium working fluid) recommended failure rates

MECHANICAL COMPONENT (SODIUM WORKING FLUID) FAILURE RATE COMPARISON

			SOURCES																				
			RECOMMENDED (A)			LMEC			LYON			PIPING SURVEY			CRBRP-4			GEFR 00554					
COMPONENTS	COMPONENT TYPE	FAILURE MODES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES			
VALVES	MANUAL	FAIL TO OPEN/CLOSE	3 0E-04 /D	5		-			2 0E-07 /H (B) OR 1 0E-06 /H (B)		1 2	-			-			-					
		PLUG	5 0E-08 /H	10		-			(C)			-			1 0E-07 /H	10	1	-					
		INTERNAL LEAKAGE	5 0E-08 /H	10		-			(C)			-			1 0E-07 /H	10	1	-					
		INTERNAL RUPTURE	1 0E-08 /H	10	0	-			(C)			-			-			-					
		EXTERNAL LEAKAGE	3 0E-07 /H	10		2 8E-06 /H		1	(C)			-			1 0E-08 /H	10		5 5E-08 /H OR 4 4E-08 /H 7 0E-14 /H		1 2 3			
		EXTERNAL RUPTURE	1 0E-08 /H	10	0	-			-			-			-			-					
	MOTOR-OPERATED	FAIL TO OPEN/CLOSE	1 0E-03 /D	5		1 2E-04 /H (B)		2	1 0E-05 /H (B)		3	-			-			-					
		SPURIOUS OPERATION	5 0E-07 /H	10		(C)			(C)			-			-			-					
		PLUG	5 0E-08 /H	10	0	(C)			(C)			-			-			-					
		INTERNAL LEAKAGE	5 0E-07 /H	10		(C)			(C)			-			-			-					
		INTERNAL RUPTURE	5 0E-08 /H	10	0	(C)			(C)			-			-			-					
		EXTERNAL LEAKAGE	5 0E-07 /H	10		2 8E-06 /H		1	(C)			-			-			-					
	PNEUMATIC/HYDRAULIC	FAIL TO OPEN/CLOSE	3 0E-03 /D	5		1 2E-04 /H (B)		2	-			-			-			1 0E-03 /D	10		3 1E-04 /D		4
		SPURIOUS OPERATION	3 0E-07 /H	10		(C)			-			-			-			1 0E-07 /H (B)	10	1	-		
		PLUG	3 0E-08 /H	10	0	(C)			-			-			-			(C)			-		
		INTERNAL LEAKAGE	1 0E-07 /H	10		(C)			-			-			-			(C)			-		
		INTERNAL RUPTURE	3 0E-08 /H	10	0	(C)			-			-			-			(C)			-		
		EXTERNAL LEAKAGE	1 0E-06 /H	10		2 8E-06 /H		1	-			-			-			1 0E-08 /H	10		3 3E-07 /H 3 3E-08 /H		5 6
	SOLENOID	FAIL TO OPEN/CLOSE	3 0E-03 /D	5	1	1 2E-04 /H (B)			-			-			-			-					
		SPURIOUS OPERATION	3 0E-07 /H	10	1	(C)			-			-			-			-					
		PLUG	3 0E-08 /H	10	1 0	(C)			-			-			-			-					
		INTERNAL LEAKAGE	1 0E-07 /H	10	1	(C)			-			-			-			-					
		INTERNAL RUPTURE	3 0E-08 /H	10	1 0	(C)			-			-			-			-					
		EXTERNAL LEAKAGE	1 0E-06 /H	10	1	2 8E-06 /H			-			-			-			-					
	CHECK	FAIL TO OPEN	1 0E-04 /D	5	0	-			-			-			-			-					
		PLUG	5 0E-07 /H	10	0	-			-			-			-			6 1E-08 /H	10		-		
		FAIL TO CLOSE	1 0E-04 /D	5	0	-			-			-			-			-			-		
		INTERNAL LEAKAGE	5 0E-07 /H	10	0	-			-			-			-			-			-		
INTERNAL RUPTURE		5 0E-07 /H	10	0	-			-			-			-			-			-			
EXTERNAL LEAKAGE		5 0E-07 /H	10	0	-			-			-			-			5 7E-08 /H	10		5 7E-06 /H 7 0E-15 /H		7 8	
RUPTURE DISC	FAIL TO OPEN	5 0E-07 /H	10	0	-			-			-			-			-			-			
	PREMATURE OPENING	1 0E-05 /H	10		3 1E-04 /H			-			-			-			-			5 0E-07 /H OR 1 3E-06 /H		9 10	

Table 2. (continued)

MECHANICAL COMPONENT (SODIUM WORKING FLUID) FAILURE RATE COMPARISON

COMPONENTS			SOURCES																	
			RECOMMENDED (A)			LMEC			LYON			PIPING SURVEY			CRBRP-4			GEFR 00554		
			MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES
PUMPS	MOTOR-DRIVEN	FAILS TO START	5 0E-03 /D	5		1 1E-04 /H (B) OR 4 0E-05 /H (B) (C)		3 4 4	1 3E-04 /H (B)	2	4	-			-			3 5E-05 /H (B) (C)		11
		FAIL TO RUN	5 0E-05 /H	10					(C)			-			-			(C)		
		EXTERNAL LEAKAGE	3 0E-06 /H	10		7 8E-07 /H		5	(C)			-			1 1E-07 /H	10		1 1E-07 /H		12
		EXTERNAL RUPTURE	5 0E-07 /H	10	0	-			-			-			-			1 4E-13 /H		13
	ELECTROMAGNETIC	FAIL TO START	3 0E-03 /D	5		2 5 E-04 /H (B)		6	1 4E-06 /H (B) OR 3 3E-05 /H (B) (C)		5 6	-			1 0E-05 /D	10		1 0E-06 /H (B) (C)		14
		FAIL TO RUN	1 0E-05 /H	10		(C)		6	(C)			-			3 7E-06 /H	10		(C)		
		EXTERNAL LEAKAGE	3 0E-06 /H	10		2 6E-07 /H		7	(C)			-			2 5E-08 /H	10		2 5E-07 /H		15
		EXTERNAL RUPTURE	3 0E-07 /H	10	0	-			-			-			-			2 5E-08 /H		16
HEAT EXCHANGERS	HX	SHELL																		
		EXTERNAL LEAKAGE	1 0E-06 /H	10	0	-			2 0E-06 /H (B)		7	-			3 8E-07 /H	10		3 8E-07 /H		17
		EXTERNAL RUPTURE	1 0E-06 /H	10	0	-			(C)			-			-			2 5E-13 /H		18
		TUBES (PER UNIT)																		
		LEAKAGE	1 0E-06 /H	10	0	1 6E-04 /H (B)		8	(C)			-			4 0E-06 /H (B)	10		4 0E-06 /H (B) (C)		19
		RUPTURE	1 0E-06 /H	10	0	(C)		8	(C)			-			(C)			(C)		
	PLUG	1 0E-06 /H	10	0	-		8	(C)			-			-			-			
	STEAM GENERATOR	SHELL																		
		EXTERNAL LEAKAGE	1 0E-06 /H	10	2	2 1E-06 /H		9	-			-			-			-		
		EXTERNAL RUPTURE	-			-			-			-			-			-		
TUBE (PER UNIT)																				
	LEAKAGE (SMALL)	5 0E-06 /H	10	3	2 9E-04 /H (B)		10	5 2E-07 /H (B)		8	-			7 0E-06 /H (B)	10		7 0E-06 /H		20	
	LEAKAGE (MEDIUM)	1 0E-06 /H	10	3	(C)		10	(C)		8	-			(C)			1 4E-06 /H		21	
	LEAKAGE (LARGE)	3 0E-07 /H	10	3	(C)		10	(C)		8	-			(C)			2 8E-07 /H		22	
	PLUG	-			-			-			-			-			-			
VESSELS	TANK	EXTERNAL LEAKAGE	1 0E-06 /H	10		5 1E-07 /H		11	-			-		8 5E-08 /H (B) OR 5 1E-08 (B) (C)	10 10 3	2 3	5 0E-08 /H OR 8 4E-08 /H 1 0E-09 /H		23 24 25	
		EXTERNAL RUPTURE	1 0E-07 /H	10	0	-			-			-			-			-		
		REACTOR VESSEL																		
		EXTERNAL LEAKAGE	1 0E-08 /H	10	3	-			-			-			1 0E-08 /H (B)	10		1 0E-08 /H		26
	GUARD VESSEL	EXTERNAL RUPTURE	1 0E-10 /H	10	3	-			-			-			(C)			1 0E-10 /H		27
		EXTERNAL LEAKAGE	1 0E-08 /H	10	4	-			-			-			1 0E-08 /H (B)	10		1 0E-08 /H		28
		EXTERNAL RUPTURE	1 0E-10 /H	10	4	-			-			-			(C)			1 0E-10 /H		29

Table 2. (continued)

MECHANICAL COMPONENT (SODIUM WORKING FLUID) FAILURE RATE COMPARISON																				
		SOURCES																		
COMPONENTS	COMPONENT TYPE	FAILURE MODES	RECOMMENDED (A)			LMEC			LYON			PIPING SURVEY			CRBRP-4			GEFR 00554		
			MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES
PIPES	1-4 INCH (PER FOOT)	LEAKAGE	3 0E-09 /H	10	5	7 6E-09 /H		12	-			2 3E-09 /H (B)		1	-			-		
		RUPTURE	3 0E-10 /H	10	5 0	-			-						-			-		
		PLUG	1 0E-09 /H	10		-			-			(C)			-			-		
	>4 INCH (PER FOOT)	LEAKAGE	3 0E-09 /H	10	5	3 0E-09 /H		13	-			2 1E-09 /H (B)		2	5 0E-10 /H		4	1 0E-09 /H OR		30
		RUPTURE	3 0E-10 /H	10	5 0	-			-			(C)			2 7E-14 /H		5	1 2E-10 /H 1 2E-15 /H		31 32
TRAPS AND STRAINERS	STRAINER/FILTER	PLUG	3 0E-06 /H	10	0	1 3E-04 /H		14	-			-			-			-		
		FAIL OPEN	3 0E-06 /H	10	0	3 3E-05 /H		15	-			-			-			-		
	COLD TRAP	FAILURE	5 0E-07 /H	10	0	-			1 0E-06 /H (B)		9	-			-			-		
		EXTERNAL LEAKAGE	5 0E-07 /H	10	0	3 6E-06 /H		16	(C)			-			-			-		
		EXTERNAL RUPTURE	5 0E-07 /H	10	0	-			-			-			-			-		
	PLUG	1 0E-05 /H	10		4 3E-05 /H		17	(C)			-			-			-			

NOTES

- (A) The recommended value was obtained from CREDO if information existed. Otherwise the value was obtained from GEFR-00554. The mean value was rounded off to 1 0E-7, 3 0E-7, or 5 0E-7.
 The range factor was estimated and rounded off to 3, 5, or 10.
 (B) This failure rate includes other failure modes.
 (C) Covered by failure rate listed above.

RECOMMENDED

- 0 Based on no failures
 1 Value for pneumatic/hydraulic valve used
 2 Value from stream generator (water/steam working fluid) used
 3 GEFR-00554 value used
 4 Value for reactor vessel used
 5 Pipe sizes not distinguished in the data search

LMEC

- 1 General value for all types of sodium valves. Obtained from Section III. Sodium Leak Experience. Nonfailed components are considered in this section. All leakages less than 10 lb of sodium.
 2 General value for all types of sodium valves. Failure modes not distinguished. Nonfailed components not considered in data base.
 3 Failure rate for centrifugal free surface pump. Failure modes not distinguished. Nonfailed components not considered.
 4 Failure rate for freeze seal pump. Failure modes not distinguished. Nonfailed components not considered.
 5 General value for all mechanical pumps. Obtained from Section III. Nonfailed components considered. All leakages less than 10 lb of sodium.
 6 Failure mode not distinguished. Nonfailed components not considered.
 7 Obtained from Section III. Nonfailed components not considered. All leakages less than 10 lb of sodium.
 8 Nonfailed components not considered. Leakage size unknown.
 9 Obtained from Section III. Nonfailed components considered. Leakage less than 10 lb of sodium.
 10 Assuming 18 out of 48 failures (38%) were tube related. Assuming 62 000 h of operation. Nonfailed components not considered. Leakage sizes unknown.
 11 Obtained from Section III. Nonfailed components considered. Leakage less than 10 lb of sodium.
 12 Tables 1-203 through 1-208 indicate 4 leakages in 1- to 4-in piping in 5 26E+8 ft-h. Nonfailed components are considered. Leakage less than 10 lb of sodium.
 13 Tables 1-203 through 1-208 indicate 1 leakage in greater than 4-in piping in 3 31E+8 ft-h. (This includes associated pipe fittings.) Nonfailed components are considered. Leakage less than 10 lb of sodium.
 14 Data for strainers. Nonfailed components not considered.
 15 Data for strainers. 0 failures in 15 000 h of operation. Nonfailed components not considered.
 16 Tables 1-203 through 1-208 indicate 3 leakages in 825 200 h of operation. Nonfailed components are considered. Leakages less than 10 lb of sodium.
 17 Table 1-69 indicates 1 plugging failure in 23 859 h of operation. Nonfailed components are not considered.

Table 2. (continued)

LYON				
1	Failure rate for frozen seal valves	Failure modes not distinguished		
2	Failure rate for bellows valves	Failure modes not distinguished		
3	Failure rate for motor	Failure modes not distinguished		
4	Failure modes not distinguished	Failure contributions are as follows		
	Mechanical	3 OE-5/HR	RF=2	
	Motor	2 OE-5/HR	RF=2	
	Control System	8 OE-5/HR	RF=2	
5	Failure rate for induction pump	Failure modes not distinguished		
6	Failure rate for conduction pump	Failure modes not distinguished		
7	Failure mode not distinguished			
8	Assuming 2 extra failures since the paper was published	Three failures in 160 000 plant hours	Six evaporators and 6 superheaters per loop and 3 loops	
9	Failure modes not distinguished	Zero failures in 491 000 h of operation		
PIPING SURVEY				
1	Nine leakages in 304 SS piping considered applicable	449 000 ft-yr of operation	Actual size range is 1 to 3 1/2-in piping	Leakage size not distinguished
2	Two leakages in 304 SS piping considered applicable	107 000 ft-yr of operation	Actual size range is 3 1/2- to 16-in piping	Leakage sizes not distinguished
GEFR-00554				
1	Failure rate data for primary drain valve obtained from 6 1a Appendix A	This is based on 2 drain valves per loop		
2	Failure rate data for intermediate drain valve obtained from 2 5 Appendix A	This is based on 5 valves per loop		
3	Failure rate data for DHRS sodium drain valve obtained from 6 1 b Appendix A	This is based on 2 drain valves per loop		
4	Failure rate data for SCS AOV obtained from 3 6 c Appendix A	This is based on 6 valves per loop		
5	Failure rate data for SCS AOV obtained from 3 6 a Appendix A	This is based on 6 valves per loop		
6	Failure rate data for SCS AOV obtained from 3 6 b Appendix A	This is based on 6 valves per loop		
7	Failure rate data for primary check valve obtained from 1 4 a Appendix A			
8	Failure rate data for primary check valve obtained from 1 4 b Appendix A			
9	Failure rate data for Sodium Relief System rupture disc obtained from 3 3 a Appendix A			
	This value is based on 3 pairs of rupture disc per loop Large rupture			
10	Failure rate data for Sodium Relief System rupture disc obtained from 3 3 b Appendix A of CRBRP-GEFR-0054	(reliability data for the CRBRP shutdown heat removal system)		
	This value is based on 3 pairs of rupture disc per loop Small rupture			
11	Failure rate data for primary pony motor obtained from 1 5 c Appendix A	This value includes the failure rate value for fails to run	Also failure rate data for intermediate pony motor obtained from 2 2 b Appendix A	
	This value includes the failure rate value for fails to run			
12	Failure rate data for primary motor-driven pump obtained from 1 5 a Appendix A of CRBRP-GEFR-0054			
	Also failure rate data for intermediate motor-driven pump obtained from 2 2 a Appendix A of CRBRP-GEFR-0054			
13	Failure rate data for primary motor-driven pump obtained from 1 5 b Appendix A of CRBRP-GEFR-0054			
14	Failure rate data for NaK electromagnet pump obtained from 6 5 b Appendix A of CRBRP-GEFR-0054	This value includes the failure rate value for fails to run	Also failure rate data for sodium electromagnet pump obtained from 6 10 a Appendix A	
15	Failure rate data for NaK electromagnet pump obtained from 6 5 a Appendix A			
16	Failure rate data for sodium electromagnet pump obtained from 6 10 b Appendix A			
17	Failure rate data for primary side of IHX-leakage of primary sodium shell obtained from 1 7 a Appendix A of CRBRP-GEFR-0054	(reliability data for the CRBRP shutdown heat removal system)		
18	Failure rate data for primary side of IHX-shell rupture obtained from 1 7 b Appendix A			
	Rupture of the IHX shell in one loop with extensive spillage of primary sodium			
19	Failure rate data for intermediate heat exchanger-tube leakage obtained from 2 4 Appendix A			
	Tube side leakage of IHX causing loop outage precluding shutdown heat removal			
20	Failure rate data for steam generator module- water-to-sodium leakage (small) obtained from 3 2 a Appendix A			
21	Failure rate data for steam generator module- water-to-sodium leakage (medium) obtained from 3 2 b Appendix A			
22	Failure rate data for steam generator module- water-to-sodium leakage (large) obtained from 3 2 c Appendix A			
23	Failure rate data for DHRS sodium tank obtained from 6 1 a Appendix A			
24	Failure rate data for NaK expansion tank obtained from 6 6 a Appendix A			
25	Failure rate data for DHRS sodium tank obtained from 6 1 b Appendix A			
	Failure rate data for NaK expansion tank obtained from 6 6 b Appendix A			
26	Failure rate data for reactor vessel obtained from 1 1 a Appendix A			
27	Failure rate data for reactor vessel obtained from 1 1 b Appendix A			
28	Failure rate data for guard vessel obtained from 1 2 a Appendix A			
29	Failure rate data for guard vessel obtained from 1 2 b Appendix A			
30	Failure rate data for primary pipe >4 in. obtained from 1 3 a Appendix A			
31	Failure rate data for intermediate sodium pipe >4 in. obtained from 2 1 Appendix A			
	This value is based on 13 5 ft per section from PHTS There are 50 sections per loop			
32	Failure rate data for primary pipe >4 in. obtained from 1 3 b Appendix A			
CRBRP-4				
1	Failure mode is transfers (open/closed)			
2	Na tank			
3	NaK tank			
4	PHTS piping small break (0.02 to 33 gpm)	Table 5 5-5		
5	PHTS piping large break (>33gpm)	Table 5 5-5		

Table 3. Mechanical component (air or gas working fluid) recommended failure rates

MECHANICAL COMPONENT (AIR OR GAS WORKING FLUID) FAILURE RATE COMPARISON																			
		SOURCES																	
COMPONENTS	FAILURE MODES	RECOMMENDED (A)			ASEP			BROOKHAVEN (IREP/NREP)			IEEE STD-500 (B)			SEABROOK PRA (C)			WASH-1400		
		MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES
FANS	VENTILATORS FAIL TO START FAIL TO RUN EXTERNAL LEAKAGE	5 0E-03 /D 3 0E-05 /H -	5 10	N1 N1	- - -	- - -	- - -	- - -	- - -	- - -	2 5E-06 /H (D) (E) (E)	1 1 1	1 1 1	4 8E-04 /D 7 9E-06 /H (D) (E)	5 2 5 1	1 1 1	- - -	- - -	- - -
	COOLER UNITS FAIL TO START FAIL TO RUN EXTERNAL LEAKAGE	1 0E-02 /D 1 0E-05 /H -	5 10	N1 N1	- - -	- - -	- - -	6 0E-06 /H (D) (E) (E)	3 7 1 1	1 1 1	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
COMPRESSORS/ BLOWERS	FAIL TO START FAIL TO RUN EXTERNAL LEAKAGE	5 0E-03 /D 1 0E-04 /H -	5 10	N1 N1	- - -	- - -	- - -	- - -	- - -	- - -	3 0E-04 /H (D) (E) (E)	31 2 2	2 2 2	3 3E-03 /D 9 8E-05 /H -	7 4 4 8 -	- - -	- - -	- - -	- - -
DAMPERS	FAIL TO OPEN/CLOSE SPURIOUS OPERATION EXTERNAL LEAKAGE	3 0E-03 /D 3 0E-07 /H -	5 10	N1 S	- - -	- - -	- - -	1 0E-06 /H - -	15 8 - -	- - -	1 5E-06 /H (D) (E) (E)	2 2 2	3 3 3	1 5E-03 /D OR 2 7E-04 /D 2 7E-07 /H OR 1 0E-08 /H -	3 1 4 4 7 3 3	2 3 2 3	- - - -	- - - -	- - - -
VESSEL	TANK PRESSURIZED EXTERNAL LEAKAGE	1 0E-05 /H	10	I	-	-	-	-	-	-	1 4E-05 /H	50	4	-	-	-	-	-	-
	ACCUMULATOR EXTERNAL LEAKAGE	5 0E-06 /H	10	I	-	-	-	-	-	-	5 5E-06 /H	-	5	-	-	-	-	-	-
FILTERS	PLUG INTERNAL RUPTURE	1 0E-05 /H -	10	I	- -	- -	- -	- -	- -	- -	2 0E-05 /H -	50	6	1 1E-06 /H -	10	4	- -	- -	- -
AIR DRYERS	FAIL TO START FAIL TO RUN	5 0E-06 /H (D) (E)	10	N1	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
AIR COND UNITS	FAIL TO START FAIL TO RUN	1 0E-02 /D 3 0E-05 /H	5 10	N1 N1	- -	- -	- -	- -	- -	- -	- -	- -	- -	8 1E-03 /D 9 4E-05 /H	5 3	5 5	- -	- -	- -

NOTES

- Recommended value obtained from NUCLARR if available. If not, then IEEE, Seabrook, or WASH-1400 value was used. Mean values rounded to 1 0E-?, 3 0E-?, or 5 0 E-?
- Error factor estimated and rounded off to 3, 5, or 10.
- For all IEEE entries, the RECOMMENDED value was interpreted to be a median value, while the high and low values were interpreted to be the 95th percent and five percent values. The range factor was obtained from the high and low values, if given. For cases in which the low value is zero, the high and median values were used.
- Error factor obtained from 95th and median values.
- This failure rate included other failure modes covered by failure rate listed above.

Table 3. (continued)

RECOMMENDED

- NI Value from NUCLARR category 1 sources.
- I Value from IEEE Std-500.
- S Value from Seabrook PRA.

BROOKHAVEN

- 1 Value is for air cooler.

IEEE STD-500

- 1 Composite of all fan data. All modes of failure.
- 2 Composite of all compressor data. All modes of failure. Smaller size compressors have significantly lower failure rates.
- 3 All modes of failure.
- 4 All modes of failure. Error factor reduced by engineering judgement.
- 5 All modes of failure. Median value.
- 6 Composite of all filter data. Error factor reduced by engineering judgement. All modes of failure.

SEABROOK

- 1 Value is for ventilation fan.
- 2 Value is for pneumatic damper.
- 3 Value is for backdraft damper.
- 4 Value is for ventilation filter.
- 5 Valve is for control room ventilation chiller.

Table 4. Electrical component recommended failure rates

ELECTRICAL COMPONENT FAILURE RATE COMPARISON

		SOURCES																	
COMPONENTS	FAILURE MODES	RECOMMENDED (A)			ASEP			BROOKHAVEN (IREP/NREP) (B)			IEEE STD-500 (C)			SEABROOK PRA			WASH-1400		
		MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES
ALARMS	GENERAL FAIL TO OPERATE SPURIOUS OPERATION	1 0E-06 /H 3 0E-06 /H	10 10	N3 N3	- -			- -			2 5E-06 /H 1 7E-06 /H	16 15		- -			- -		
BATTERIES AND CHARGERS	RECTIFIER FAILURE	1 0E-05 /H	5	N1	4 0E-04 /D	3	1	6 0E-07 /H	3 6	1	4 4E-06 /H	14		1 9E-05 /H	6 5	1	-		
	MOTOR-GENERATOR FAILURE	1 0E-05 /H	5	N1	4 0E-04 /D	3	1	3 0E-06 /H	18 3	2	4 3E-05 /H	2		3 6E-05 /H	10 9		-		
	PRIMARY BATTERIES FAILURE	1 0E-05 /H	5	N1	4 0E-04 /D	3	2	2 0E-06 /H	3 5	3	1 2E-05 /H	17	1	7 5E-07 /H	4 3	2	-		
	SECONDARY BATTERIES STORAGE FAILURE	1 0E-05 /H	5	N1	4 0E-04 /D	3	2	2 0E-06 /H	3 5	3	6 4E-06 /H	21	1	7 5E-07 /H	4 3	2	3 8E-06 /H	3	1
CIRCUIT BREAKERS	INDOOR FAIL TO OPEN	5 0E-04 /D	10	N1	-			1 0E-05 /H	15 8		3 2E-03 /D	42		8 4E-04 /D	10	3	1 2E-03 /D (D)	3	2
	FAIL TO CLOSE	5 0E-04 /D	10	N1	-			1 0E-05 /H	15 8		7 4E-03 /D	42		2 3E-04 /D	10	3	(E)		
	SPURIOUS OPERATION	3 0E-07 /H	10	N1	-			3 0E-05 /H	18 3		2 9E-06 /H	45		2 7E-07 /H	6 8	3	1 2E-06 /H	3	3
	OUTDOOR FAIL TO OPEN	5 0E-04 /D	10	N1	-			-			-			6 5E-04 /D	3 8	4	-		
	FAIL TO CLOSE	5 0E-04 /D	10	N1	-			-			-			1 6E-03 /D	3 2	4	-		
	SPURIOUS OPERATION	3 0E-07 /H	10	N1	-			-			-			8 3E-07 /H	6	4	-		
RELAYS	GENERAL FAIL TO OPEN	3 0E-04 /D	10	S	-			1 0E-06 /H	15 8		5 6E-06 /D	10		2 4E-04 /D	6 8		1 2E-04 /D (D)	3	4
	FAIL TO CLOSE	3 0E-04 /D	10	S	-			1 0E-06 /H	15 8		5 3E-06 /D	10		2 4E-04 /D	6 8		(E)		
	SPURIOUS OPERATION	5 0E-07 /H	10	S	-			3 0E-06 /H	18 3		1 7E-06 /H	50	2	4 2E-07 /H	6 6	5	2 7E-07 /H	10	5
	PROTECTIVE FAIL TO OPEN	3 0E-04 /D	10	S	-			-			6 6E-07 /D	3		-			-		
	FAIL TO CLOSE	3 0E-04 /D	10	S	-			-			3 7E-06 /D	3		-			-		
	SPURIOUS OPERATION	5 0E-07 /H	10	S	-			-			2 5E-07 /H	30	2	-			-		
	CONTROL OR SEQUENTIAL FAIL TO OPEN	3 0E-04 /D	10	S	-			1 0E-05 /H	7 1	4	3 4E-06 /D	2		-			-		
	FAIL TO CLOSE	3 0E-04 /D	10	S	-			1 0E-05 /H	7 1	4	4 3E-06 /D	2		-			-		
	SPURIOUS OPERATION	5 0E-07 /H	10	S	-			1 0E-06 /H	15 8	4	4 8E-07 /H	50	2	-			-		
	BISTABLE FAIL TO OPEN/CLOSE	3 0E-07 /D	5	I	-			-			3 0E-07 /D	2		3 9E-07 /D	3 9		-		
	SPURIOUS OPERATION	3 0E-07 /H	10	I	-			-			3 8E-07 /H	6		2 2E-06 /H	41 7		-		

Table 4. (continued)

ELECTRICAL COMPONENT FAILURE RATE COMPARISON

		SOURCES																	
COMPONENTS	FAILURE MODES	RECOMMENDED (A)			ASEP			BROOKHAVEN (IREP/NREP) (B)			IEEE STD-500 (C)			SEABROOK PRA			WASH-1400		
		MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES
SWITCHES	GENERAL FAIL TO OPEN FAIL TO CLOSE SPURIOUS OPERATION	1 0E-05 /D	5	W	-			-			2 8E-07 /D	21		-			-		
		1 0E-05 /D	5	W	-			-			3 0E-08 /D	11		-			-		
		1 0E-06 /H	10	I	-			-			4 2E-06 /H	50	2	-			-		
	LIMIT FAIL TO OPEN FAIL TO CLOSE SPURIOUS OPERATION	3 0E-05 /D	5	N1	-			6 0E-06 /H (D)	7	1	7 9E-06 /H (D)	2		-			3 8E-04 /D (D)	3	
		3 0E-05 /D	5	N1	-			(E)			(E)			-			(E)		
		1 0E-06 /H	10	N1	-			(E)			(E)			-			-		
	PUSH-BUTTON FAIL TO OPEN FAIL TO CLOSE SPURIOUS OPERATION	1 0E-05 /D	5	W	-			1 0E-06 /H (D)	15	8	1 7E-06 /H	15		-			1.2E-05 /D (D)	3	6
		1 0E-05 /D	5	W	-			(E)			-			-			(E)		
		1 0E-06 /H	10	I	-			(E)			9 4E-07 /H	13		-			-		
BUS	METAL-ENCLOSED FAILURE	1 0E-07 /H	5	I	9.0E-05 /D	5	3	3 0E-08 /H	18	3	1 3E-07 /H	5		5 0E-07 /H	3.3		-		
	OUTDOOR (BARE) FAILURE	1 0E-06 /H	10	I	9.0E-05 /D	5	3	-			8 5E-07 /H	12		-			-		
FUSES	FAIL TO OPEN PREMATURE OPENING	1 0E-05 /D 1 0E-07 /H	10 10	W N3	- -			- 3.0E-06 /H	18	3	3 2E-08 /H (D) (E)	5		- 9 2E-07 /H	8	8	1.2E-05 /D 1 2E-06 /H	3 3	7 7
MOTORS	AC FAIL TO START FAIL TO RUN	3 0E-05 /D 3.0E-05 /H	10 10	I I	- -			- -			3 5E-05 /D 2 7E-05 /H	4 30	2	- -			3 8E-04 /D 1.2E-05 /H	3 3	8 9
	DC FAIL TO START FAIL TO RUN	- -			- -			- -			1 3E-04 /H (D) (E)	30	2	- -			- -		
INVERTER	FAILURE	1 0E-02 /D OR 5 0E-06 /H	5 5	N1 N1	4 0E-02 /D	3		6 0E-05 /H	3	7	1 3E-05 /H	13		1 8E-05 /H	3.9		-		
HEATERS	AIR FAIL TO HEAT OVERHEAT	5 0E-06 /H 1 0E-06 /H	10 10	I I	- -			- -			4 4E-06 /H 1.2E-06 /H	15 19		- -			- -		
	IMMERSION FAIL TO HEAT OVERHEAT	1 0E-06 /H 1 0E-07 /H	10 10	I I	- -			- -			1 7E-06 /H 1 2E-07 /H	21 15		- -			- -		
	PIPE FAIL TO HEAT OVERHEAT	1 0E-06 /H -	10	I	- -			- -			7 0E-07 /H -	3		- -			- -		
TRANSFORMERS	STATION SERVICE FAILURE	1 0E-06 /H	10	N1	-			6 00E-07 /H	3	7	1 1E-06 /H OR 1 0E-07 /H	18 19		6 9E-07 /H	3	1	1 0E-06 /H	3	10
	MAIN POWER FAILURE	1 0E-06 /H	10	N1	-			-			5 6E-07 /H OR 3 1E-08 /H	4 3		1 6E-06 /H	3	4	1 0E-06 /H	3	10
	INSTRUMENT FAILURE	1 0E-06 /H	10	N1	-			-			3 1E-07 /H OR 8 7E-08 /H	3 2		1 6E-06 /H	7		1 2E-06 /H	3	

Table 4. (continued)

ELECTRICAL COMPONENT FAILURE RATE COMPARISON

COMPONENTS	FAILURE MODES	SOURCES																	
		RECOMMENDED (A)			ASEP			BROOKHAVEN (IREP/NREP) (B)			IEEE STD-500 (C)			SEABROOK PRA			WASH-1400		
		MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES
INSTRUMENT CONTROL AND SENSORS	TEMP ELEMENT FAILURE	1 0E-06 /H	10	N1	-			-			4 0E-06 /H	8		-			-		
	TEMP TRANSMITTER FAILURE	3 0E-06 /H	10	N1	-			-			1 4E-06 /H	4		-			2 7E-06 /H	10	11
	TEMP PROCESS SWITCH FAIL TO OPEN/CLOSE SPURIOUS OPERATION	3 0E-07 /D 1 0E-06 /H	10 10	N3 N1	- -			- -			1 5E-07 /D 2 9E-07 /H	3 3		- -			- -		
	PRESS ELEMENT FAILURE	1 0E-06 /H	10	N1	-			-			1 9E-06 /H	16		-			-		
	PRESS TRANSMITTER FAILURE	3 0E-06 /H	10	N1	-			-			1 4E-06 /H	3		7 6E-06 /H	4 2		2 7E-06 /H	10	11
	PRESS PROCESS SWITCH FAIL TO OPEN/CLOSE SPURIOUS OPERATION	3 0E-07 /D 1 0E-06 /H	10 10	N3 N1	- -			- -			1 5E-07 /D 1 0E-07 /H	3 4		2 7E-04 /D -			- -		
	FLOW ELEMENT FAILURE	1 0E-06 /H	10	N1	-			-			7 6E-07 /H	9		-			-		
	FLOW TRANSMITTER FAILURE	3 0E-06 /H	10	N1	-			-			1 6E-06 /H	2		6 3E-06 /H	3 2		2 7E-06 /H	10	11
	FLOW PROCESS SWITCH FAIL TO OPEN/CLOSE SPURIOUS OPERATION	3 0E-07 /D 1 0E-06 /H	10 10	N3 N1	- -			- -			1 4E-08 /D 1 2E-06 /H	4 4		- -			- -		
	LEVEL ELEMENT FAILURE	1 0E-06 /H	10	N1	-			-			-			-			-		
	LEVEL TRANSMITTER FAILURE	3 0E-06 /H	10	N1	-			-			1 5E-06 /H	2		1 6E-05 /H	2 7		2 7E-06 /H	10	11
	LEVEL PROCESS SWITCH FAIL TO OPEN/CLOSE SPURIOUS OPERATION	3 0E-07 /D 1 0E-06 /H	10 10	N3 N1	- -			- -			3 3E-08 /D 1 7E-06 /H	2 2		- -			- -		
	SPEED TRANSDUCER FAILURE	1 0E-06 /H	10	I	-			-			1 3E-06 /H	4		-			-		
	RADIATION FAILURE	5 0E-06 /H	10	I	-			-			6 6E-06 /H	5		-			-		
	MODIFIER (AC DC ANALOG DIGITAL COMPUTATION ETC) FAILURE	3 0E-06 /H	10	S	-			-			3 3E-07 /H	2		2 9E-06 /H	3 6		-		
	INDICATOR FAILURE	1 0E-06 /H	10	I	-			-			1 4E-06 /H	2		-			-		
	POWER SUPPLY FAILURE	1 0E-05 /H	10	S	-			-			7 0E-06 /H	9		1 7E-05 /H	6 4		-		
	AMPLIFIER FAILURE	5 0E-06 /H	10	S	-			-			1 5E-06 /H	15		6 2E-06 /H	2 3		-		

Table 4. (continued)

ELECTRICAL COMPONENT FAILURE RATE COMPARISON

COMPONENTS	FAILURE MODES	SOURCES																	
		RECOMMENDED (A)			ASEP			BROOKHAVEN (IREP/NREP) (B)			IEEE STD-500 (C)			SEABROOK PRA			WASH-1400		
		MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES	MEAN	ERROR FACTOR	NOTES
CABLES JOINTS AND TERMINATIONS	COPPER CABLES (PER CIRCUIT)																		
	OPEN CIRCUIT	1 0E-07 /H (D)	10	N1	-			1 0E-05 /H	15 8	5	3 4E-07 /H		3	4 6E-06 /H (D)	3 5		3 8E-06 /H	3	12
	SHORT CIRCUIT	(E)			-			1 0E-06 /H	15 8	5	7 2E-06 /H	11		(E)			8 0E-07 /H	10	12
	COPPER JOINTS																		
	OPEN CIRCUIT	5 0E-06 /H (D)	10	I	-			-			4 5E-06 /H (D)	39		-			-		
	SHORT CIRCUIT	(E)			-			-			(E)			-			-		
	COPPER TERMINATIONS (PER TERMINAL)																		
	OPEN CIRCUIT	5 0E-06 /H	10	I	-			3 0E-07 /H	18 3	6	5 4E-06 /H	5		-			2 7E-07 /H	10	13
	SHORT CIRCUIT	5 0E-06 /H	10	I	-			3 0E-07 /H	18 3	6	5 0E-06 /H	5		-			2 7E-08 /H	10	14
SOLID STATE LOGIC MODULE	FAILURE	3 0E-06 /H	10	W	-			3 0E-06 /H	18 3		-			-			2 7E-06 /H	10	
REACTOR TRIP	BREAKER FAIL TO OPEN	5 0E-03 /D	5	S	-			-			-			4 7E-03 /D	3		-		

NOTES

- (A) Recommended value obtained from NUCLARR if available. Otherwise value obtained from IEEE Seabrook or WASH-1400. Mean value rounded off to 1 0E-7, 3 0E-7 or 5 0E-7. Error factor estimated based on error factors of comparison sources and rounded off to 3, 5 or 10.
- (B) Error factor was obtained from square root of maximum value/minimum value.
- (C) Recommended value was interpreted as median.
- (D) This value includes several failure modes.
- (E) See value above (covers several failure modes).

RECOMMENDED

- N1 NUCLARR data base category 1 sources (PRAS)
- N2 NUCLARR data base category 2 sources (LERS IPRDS)
- N3 NUCLARR data base category 3 sources (IEEE NPRD-3)
- S Seabrook PRA
- I IEEE Std-500
- W WASH-1400

ASEP

- 1 General number for charger
- 2 General number for battery
- 3 General number for bus

BROOKHAVEN

- 1 Battery charger
- 2 DC motor generator
- 3 General number for battery
- 4 Time delay relay
- 5 Per circuit
- 6 Per terminal

Table 4. (continued)

IEEE Std-500

- 1 Value for all modes of failure including catastrophic degraded and incipient
- 2 IEEE range factor reduced by engineering judgement
- 3 Median value No range factor indicated

SEABROOK

- 1 Battery charger
- 2 General number for battery
- 3 AC or DC, less than 480V
- 4 AC, greater than 480V.
- 5 Fail during operation

WASH-1400

- 1 Failure mode involves failure to provide proper output
- 2 For general circuit breaker Failure to transfer failure mode
- 3 For general circuit breaker.
- 4 Failure to energize failure mode
- 5 Value for contact short/open circuit and coil failures
- 6 Value for manual switch
- 7 No size or indoor/outdoor distinction
- 8 No AC/DC distinction
- 9 No AC/DC distinction For normal environment.
- 10 For general instrument Failure to operate failure mode Includes element and transmitter and possibly a process switch (output device)
- 11 Value for pressure switch
- 12 Value for typical circuit.
- 13 Value for termination board terminal
- 14 See Note 12. Short to adjacent circuit failure mode

Table 5. Classification of NUCLARR sources

Category 1 (Plant-Specific Data from PRAs and Reliability Studies)

132-85 (SWD-HBK)	212-81 (NEE3-PRA)	222-89 (C-PRA)
211-85 (MNS1-PRA)	213-81 (ZIS-PRA)	223-89 (D-PRA)
205-86 (HNP1-PRA)	209-82 (IPS-PRA)	224-89 (E-PRA)
216-87 (X-PRA)	134-89 (A-REL)	225-89 (F-PRA)
217-87 (EUR-PRA)	135-89 (B-REL)	226-89 (G-PRA)
218-87 (Y-PRA)	220-89 (A-PRA)	
200-81 (BRP1-PRA)	221-89 (B-PRA)	

Category 2 (LER Surveys and IPRD)

128-83 (IPRDS)	133-86 (NSAC-108)	63-82 (LER-SUMM)
65-84 (LER-SUMM)	135-87 (PBS)	36-85 (IPRDS)
67-84 (LER-SUMM)	129-82 (IPRDS)	
36-85 (IPRDS)	62-82 (LER-SUMM)	

Category 3 (Others)

134-85 (RAC-85)	54-75 (WASH-1400)	53-83 (IEEE-500)
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Table 6. NUCLARR mechanical component (water, steam, air, or gas working fluid) failure rates

COMPONENT/ FAILURE MODE	CATEGORY 1 (PRAS)						CATEGORY 2 (LERS IPRD)						CATEGORY 3 (OTHER)						
	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	ERROR FACTOR	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	ERROR FACTOR	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	MEDIAN	ERROR FACTOR
VALVES																			
-MANUAL																			
fail to operate	16	38	87790		4 3E-04	16 1	3	9	64873		1 5E-04	19 1							
fail to operate	16	7		210557776	3 3E-08	87 5													
spurious operation	3	1		12029265	1 2E-07	3 2	1	1		876000	1 7E-06	3 2							
blocked							1	0		137818032	3 6E-09	5 6							
-MOTOR OPERATED																			
fail to operate	31	390	123701		3 2E-03	7 0	7	287	74886		3 8E-03	3 5							
fail to operate	10	15		3140959	4 8E-06	9 6													
fail to open	5	44	7135		6 1E-03	1 5													
fail to close	6	46	10638		4 3E-03	3 7													
spurious operation	7	1		20941481	7 2E-08	3 2	6	24		137012872	1 8E-07	17 4							
-PNEUMATIC																			
fail to operate	18	110	93651		1 2E-03	21 2	6	85	28503		3 0E-03	3 2							
fail to operate	10	1		2603842	5 2E-07	2 6													
fail to open	1	0	167		3 0E-03	5 6													
spurious operation	7	13		6205361	2 1E-06	3 2	5	19		32622736	6 0E-07	3 7							
external leakage							1	2		19322736	1 3E-07	2 6							
Internal leakage	1	8		5348898	1 6E-06	1 7	4	8		14000000	6 1E-07	2 2							
-SOLENOID																			
fail to operate	8	2	3473		7 2E-04	2 6	2	96	8963		1 1E-02	2 2	2	---	---		4 7E-06	---	19 3
fail to operate	10	16		23120464	7 2E-07	1 2													
spurious operation	1	0		812000	6 2E-07	5 6	1	1		88000	1 7E-05	3 2							
-VACUUM BREAKER																			
fail to operate	2	0	45		1 1E-02	5 5													
fail to operate	2	0		1143	4 4E-04	5 6													
-CHECK VALVES																			
fail to operate	66	120	119599		1 0E-03	9 7	1	3	46544		7 5E-05	2 3							
fail to operate	4	0		504573	9 9E-07	5 6													
fail to open	12	1	25170		6 0E-05	3 2	1	3	46544		7 5E-05	2 3							
fail to close	7	18	9042		1 5E-03	3 2													
leakage	35	36		11522400	3 1E-06	37 0	2	60		203133696	3 0E-07	7 0							
-RELIEF VALVES																			
fail to operate	30	19	7700		2 5E-03	2 9	35	181	38061		4 8E-03	8 3							
fail to operate	15	0		5395107	8 5E-08	5 6													
fail to open	19	7	3133		2 2E-03	2 1	20	130	11253		1 2E-02	2 9							
fail to open	16	0		5879394	8 5E-08	5 6													
-MECH VALVES (SPRING OPERATOR)																			
spurious operation	1	8		184104	4 6E-05	1 7													
-HYDRAULIC VALVES																			
fail to operate	4	11	4890		2 2E-03	2 6													
fail to operate	2	0		269310	1 9E-06	5 6													
spurious operation	1	0		274000	1 8E-06	5 6													
-UNKNOWN OP VALVES																			
fail to operate	9	64	4400		1 4E-02	5 7													
fail to operate	1	18		148479	1 2E-04	1 5													
-TANKS																			
external leakage	1	0		689000	7 3E-07	5 6							0	---	---		---	1 8E-05	---
-STRAINERS																			
plugged	1	2		602000	4 2E-06	2 6													
-STRUCTURAL FUNCTION ITEMS																			
external leakage													0	---	---		---	1 2E-06	---

Table 6. (continued)

COMPONENT/ FAILURE MODE	CATEGORY 1 (PRAS)						CATEGORY 2 (LERS IPRD)						CATEGORY 3 (OTHER)						
	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	ERROR FACTOR	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	ERROR FACTOR	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	MEDIAN	ERROR FACTOR
-PUMPS (STD) fail to operate fail to operate fail to start fail to run fail to run leakage	20 15 19 1 9	45 22 45 0 19	2034 2001 33	 202126 138526	2 2E-02 1 1E-04 2 2E-02 1 5E-02 1 4E-04	4 0 22 3 3 9 5 5 21 5	3 3 3 1	72 72 22 1	7138 7138 222906 3472686	 222906 3472686	1 0E-02 1 0E-02 1 0E-04 4 3E-07	1 1 1 1 1 7 3 2							
-PUMPS (MOTOR DRIV) fail to start fail to run leakage	94 71	137 216	48459	 7462039	2 8E-03 2 9E-05	5 7 16 3	27 43 3	84 242 117	103806	 23714387 56763604	8 1E-04 1 0E-05 2 1E-06	9 3 4 6 2 3							
-PUMPS (DIESEL DRIV) fail to start fail to run leakage	5 2	15 3	1897	 647	7 9E-03 4 6E-03	5 8 7 4	6 1	10 0	1136	 153566	9 2E-03 3 3E-06	13 8 5 6							
-PIPE external leak	42	20		141165000	1 4E-07	5 5													
-MISC PIPING leakage													1	---		---	---	1 8E-05	---
-HEAT EXCHANGERS plugged external leakage internal leakage	5 1 2	0 0 0		1905000 1590000 384000	2 6E-07 3 1E-07 1 3E-06	5 6 5 6 5 6							5	---		---	3 3E-05	---	2 6
-FANS/VENTILATORS fail to start fail to run	3 2	11 13	1501	 520800	7 3E-03 2 5E-05	3 7 3 7							8	166		35670000	4 7E-06	---	10 3
-FILTERS plugged													2	---		---	4 8E-06	---	4 7
-FITTINGS leak													1	---		---	---	1 9E-05	---
-FANS/COOLER UNITS fail to start fail to run	4 2	21 2	2489	 226000	8 4E-03 8 8E-06	7 2 2 9													
-DAMPERS(UNKNOWN OP) fail to operate	1	3	1155		3 0E-03	2 3													
-CONTROL ROD DRIVES fail to operate fail to operate	1 2	0 85	610	 162544	8 2E-04 5 2E-04	5 6 2 1													
-CONTROL RODS fail to operate	1	1		33131538	4 5E-08	3 2													
-BLOWERS/COMPRESSORS fail to start fail to run	3 4	10 23	1368	 301356	7 3E-03 7 6E-05	9 5 1 3							1	22		101000	2 2E-04	---	1 4
-AIR DRYERS fail to run	1			86100	5 8E-06	5 6													
-AIR COND UNITS fail to start fail to run	2 3	8 4	612	 191626	1 3E-02 2 2E-05	1 0 2 5													
-ACCUMULATORS external leakage													0	---		---	---	1 7E-06	---

Table 7. NUCLARR electrical component failure rates

COMPONENT/ FAILURE MODE	CATEGORY 1 (PRAS)						CATEGORY 2 (LERS (PRD))						CATEGORY 3 (OTHER)					
	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	ERROR FACTOR	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	ERROR FACTOR	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	ERROR FACTOR
-AUTO TRANS SWITCH fail to operate	1	1	75		2 0E-2	3 2												
-ANNUNCIATORS fail to operate spurious													1 1	---		---	9 0E-7 3 0E-6	8 4 8 6
-BATTERIES fail to operate fail to operate	2 6	7 8	591		1 2E-2 8 5E-6	1 9 3 7				1508715	4 3E-6	2 9	1	---		---	7 2E-8	5 9
-CHARGER BATT fail to operate	7	29		1620042	1 8E-5	1 7	5	12		2183975	5 7E-6	2 2	1	---		---	9 2E-6	45 8
-CIRCUIT BREAKERS MC fail to operate													1	---		---	2 1E-6	6 1
-CIR BRKRS POWER fail to operate fail to start fail to open fail to close fail to energize fail to de- energize spurious	8 4 3 1 1 12	85 6 7 2 1 15	170775 5220 4608 2491 876		5 1E-4 1 1E-3 1 6E-3 1 0E-3 1 7E-3 3 9E-7	5 9 7 8 1 4 2 6 3 2 1 6	1 1	19 6	56282 6948		3 5E-4 9 4E-4	1 4 1 9						
-CHANNELS fail to operate							200	---		---	1 3E-5	3 4						
-CONDUCTORS fail to operate	5	1		14144000	1 1E-7	3 2							1	---		---	1 8E-5	118 0
-COMPUTATION MOD fail to operate													7	---		---	3 8E-4	248 1
-CIRCUIT CONTROL fail to operate fail to energize	1	5		192864	2 9E-5	2 0	5	292	170078		1 7E-3	2 2						
-CONTROLLER/REGULATOR fail to operate													2	---		---	3 4E-6	8 0
-ELEC FUNCT ITEMS fail to operate	1	0		386000	1 3E-6	5 6												
-ELEC PIECE PARTS fail to operate	1	1		386000	ERR	ERR												
-FUSE spurious													1	6		48577000	1 3E-7	1 9

Table 7. (continued)

COMPONENT/ FAILURE MODE	CATEGORY 1 (PRAS)						CATEGORY 2 (LERS IPRD)						CATEGORY 3 (OTHER)					
	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	ERROR FACTOR	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	ERROR FACTOR	NO OF RECORDS	FAILURES	DEMANDS	HOURS	MEAN	ERROR FACTOR
-GENERATOR DIESEL fail to start fail to run	22 8	92 29	8746	6647	1 1E-2 4 4E-3	1 9 3 2	71 71	83 140	22174 13808		3 8E-3 1 0E-2	3 2 3 4						
-GENERATOR HYDRO-TURB fail to start	1	12	4077		3 1E-3	1 6												
-GENERATOR MOTOR DRIV fail to run	1	31		1470000	2 1E-5	1 3												
-GENERATOR GAS-TURB fail to start fail to run	2 1	35 1	940	5697	3 7E-2 2 6E-4	1 1 3 2												
-HEATERS fail to operate													1	3		395000	8 9E-6	2 2
-POWER ELECTRONICS (SOLID STATE) fail to operate fail to operate	5 9	0 37	63	8138540	7 8E-3 4 5E-6	5 5 4 2												
-RELAYS/CONTROLS fail to operate							30	90		38761	2 3E-3	6 3	4	---		---	5 5E-5	58 3
-RELAYS/PROTECTIVE fail to operate													9	683		1 816E+09	3 8E-7	1 5
-RELAYS/PROTECTIVE fail to operate													9	7075		6 955E+09	1 0E-6	1 9
-TRANSDUCERS fail to operate spurious	5 10	12 78	56557	76257100	2 8E-4 1 0E-6	3 4 3 3							2	---		---	3 3E-6	1 8
-SWITCHES INSTRUM fail to operate fail to operate spurious	1 1 1	0 7 7	12550	8160000 8160000	4 0E-5 9 2E-7 9 2E-7	5 6 1 8 1 8							2 2 2	---	---	---	1 9E-7 8 3E-7 2 5E-7	4 2 12 2 6 6
-SWITCHES SOLID STATE fail to operate spurious													2 1	---	---	---	3 7E-7 5 8E-7	3 3 10 4
-TRANSMITTERS fail to operate spurious	7	57		25934100	2 2E-6	1 4							3 3	---		---	5 4E-7 1 1E-5	4 4 19 9
-TRANSFORMERS C & I fail to operate	6	5		6190213	9 5E-7	4 0							1	---		---	6 6E-7	7 5
-TRANSFORMERS POWER fail to operate	5	1		1824900	8 2E-7	3 2							1	---		---	3 2E-7	6 5

Table 8. CREDO failure modes classification

<u>Type of Component</u>	<u>PRA Failure Mode</u>	<u>CREDO Failure Modes</u>
Pump, motor, fan	Fail to start	NOENER, NOSTART
	Fail to run	NORUN, ABNORMOP, SPURIOUS
	External leakage	PRIMLEAK, LEAK, BREACH, CRACK
Valve, circuit breaker, relay	Fail to open/close	NOCLOSE, NOMOVE, NOOPEN, NOENER, NODEENER, NOCON, SEIZED
	Spurious operation	FAILSHUT, FAILOPEN, SPURIOUS, NOHOLD
	Plugged	PLUGGED
	Internal leakage	LEAKINT
	External leakage	PRIMLEAK, LEAK, BREACH, CRACK
Pipe, vessel	External leakage	PRIMLEAK, LEAK, BREACH, CRACK
Rupture device	Premature opening	PRIMLEAK, LEAK, BREACH, CRACK

Table 9. CREDO component (sodium working fluid) failure rates

<u>Component</u>	<u>Failure Mode</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>	<u>Mean Failure Rate</u>
Manual valve	Fail to open/close	14	56923		2.6E-4/d
	Plugged	1		2.66E7	5.6E-8/h
	Internal leakage	1		2.66E7	5.6E-8/h
	Internal rupture	0		2.66E7	1.9E-8/h
	External leakage	7		2.66E7	2.8E-7/h
	External rupture	0		2.66E7	1.9E-8/h
Motor-operated valve	Fail to open/close	31	17553		1.8E-3/d
	Spurious operation	4		1.04E7	4.3E-7/h
	Plugged	0		1.04E7	4.8E-8/h
	Internal leakage	6		1.04E7	6.3E-7/h
	Internal rupture	0		1.04E7	4.8E-8/h
	External leakage	6		1.04E7	6.3E-7/h
Pneumatic valve	External rupture	0		1.04E7	4.8E-8/h
	Fail to open/close	60	28344		2.1E-3/d
	Spurious operation	4		1.50E7	3.0E-7/h
	Plugged	0		1.50E7	3.3E-8/h
	Internal leakage	2		1.50E7	1.7E-7/h
	Internal rupture	0		1.50E7	3.3E-8/h

Table 9. (continued)

<u>Component</u>	<u>Failure Mode</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>	<u>Mean Failure Rate</u>
Pneumatic valve (continued)	External leakage	13		1.50E7	9.0E-7/h
	External rupture	0		1.50E7	3.3E-8/h
Check valve	Fail to open/ close	0	2851		1.8E-4/d
	Plugged	0		7.54E5	6.6E-7/h
	Internal leakage	0		7.54E5	6.6E-7/h
	Internal rupture	0		7.54E5	6.6E-7/h
	External leakage	0		7.54E5	6.6E-7/h
	External rupture	0		7.54E5	6.6E-7/h
Rupture disk	Fail to open	0		7.77E5	6.4E-7/h
	Premature opening	6		7.77E5	8.4E-6/h
Motor- driven pump	Fail to start	8	1642		5.2E-3/d
	Fail to run	31		7.16E5	4.4E-5/h
	External leakage	1		7.16E5	2.1E-6/h
	External rupture	0		7.16E5	6.1E-7/h
Electro- magnetic pump	Fail to start	10	3504		3.0E-3/d
	Fail to run	45		2.43E6	1.9E-5/h
	External leakage	7		2.43E6	3.1E-6/h
	External rupture	0		2.43E6	2.1E-7/h
IHX heat exchanger	Shell external leakage	0		4.97E5	1.0E-6/h

Table 9. (continued)

<u>Component</u>	<u>Failure Mode</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>	<u>Mean Failure Rate</u>
IHX heat exchanger (continued)	Shell external rupture	0		4.97E5	1.0E-6/h
	Tube leakage	0		4.97E5	1.0E-6/h
	Tube plugged	0		4.97E5	1.0E-6/h
Accumulator	External leakage	1		1.62E6	9.3E-7/h
	External rupture	0		1.62E6	3.1E-7/h
Reactor vessel	External leakage	0		3.20E5	1.6E-6/h
	External rupture	0		3.20E5	1.6E-6/h
Vessel	External leakage	3		4.12E6	8.5E-7/h
	External rupture	0		4.12E6	1.2E-7/h
Pipe	External leakage	4		1.81E9ft	2.5E-9/ft-h
	External rupture	0		1.81E9ft	2.8E-10/ft-h
	Plugged	1		1.81E9ft	8.3E-10/ft-h
Filter	Plugged	0		1.76E5	2.8E-6/h
	Fail open	0		1.76E5	2.8E-6/h
Cold trap (wire mesh)	Failure	0		7.73E5	6.5E-7/h
	Plugged	9		7.73E5	1.2E-5/h
	External leakage	0		7.73E5	6.5E-7/h
	External rupture	0		7.73E5	6.5E-7/h

APPENDIX A
CREDO FAILURE EVENT REVIEW

TABLES

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Table A-1. Review of manual valve CREDO failures

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
1.	JY800005	NOMOVE		YES
2.	FF800105	OTHER		NO
3.	FF800106	OTHER		NO
4.	FF800107	OTHER		NO
5.	FF800108	OTHER		NO
6.	SC840005	ABNORMOP		NO
7.	SC840010	ABNORMOP		NO
8.	SC840014	ABNORMOP		NO
9.	JY850008	NOMOVE		YES
10.	JY870004	NOOPEN		YES
11.	SC830007	LEAKINT		NO
12.	ER870011	PRIMLEAK(small)		YES
13.	FF800094	PLUGGED		YES
14.	ER740001	NOMOVE		YES
15.	ER680001	CRACK		NO
16.	ER830007	PRIMLEAK(small)		YES
17.	FF810025	NOCLOSE		YES
18.	FF820031	FALSE		NO
19.	FF790021	ABNORMOP		NO
20.	FF810039	NOMOVE		YES
21.	FF800025	FALSE		NO
22.	FF820041	LEAKINT		YES

Table A-1. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
23.	FF800083	SPURIOUS	NOMOVE	YES
24.	FF800035	NOMOVE		YES
25.	FF850058	ABNORMOP		NO
26.	SL730003	NOMOVE		YES
27.	SL770007	LEAK(small)		YES
28.	SG770001	LEAK(small)		YES
29.	SG770006	ABNORMOP	NOMOVE	YES
30.	SG770007	ABNORMOP	NOMOVE	YES
31.	SG770008	ABNORMOP	NOMOVE	YES
32.	SG810020	LEAK(small)		YES
33.	SG760002	LEAK(small)		YES
34.	SG760007	NOOPEN		YES
35.	SG760010	LEAK(small)		YES
36.	JY770001	OTHER		NO
37.	JY800003	NOMOVE		YES
38.	FF800109	OTHER		NO

Table A-2. Manual valve summary

<u>Failure Mode</u>	<u>CREDO Failure Events</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>
Fail to open/close	NOMOVE(11), NOOPEN(2), NOCLOSE(1)	14	56923	
Plugged	PLUGGED(1)	1		2.66E7
Internal leakage	LEAKINT(1)	1		2.66E7
Internal rupture	None	0		2.66E7
External leakage	PRIMLEAK(2), LEAK(5)	7		2.66E7
External rupture	None	0		2.66E7

Table A-3. Review of motor-operated valve CREDO failures

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
1.	JY850006	NOOPEN		YES
2.	JY870002	NOOPEN		YES
3.	JY870003	NOOPEN		YES
4.	JY820001	NOOPEN		YES
5.	JY850007	NOOPEN		YES
6.	JY830001	FALSE		NO
7.	JY850005	NOOPEN		YES
8.	JY870001	NOOPEN		YES
9.	FF800002	LEAKINT(169gal/d)		YES
10.	FF810047	??	NOCLOSE	YES
11.	FF820060	ABNORMOP		NO
12.	FF820064	OUTADJ		NO
13.	FF820063	ABNORMOP		NO
14.	FF800001	NOOPEN		YES
15.	FF810038	LEAKINT		YES
16.	FF810023	NOOPEN		YES
17.	FF830047	NOCLOSE		YES
18.	FF840042	NOCLOSE		YES
19.	FF830070	NOOPEN		NO
20.	FF800024	NOOPEN		YES
21.	FF800023	NOOPEN		YES
22.	FF820042	FAILSHUT	NOOPEN	YES

Table A-3. (continued)

<u>No.</u>	<u>Event</u>	<u>FAILURE MODE</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
23.	FF820039	NOMOVE		YES
24.	SF750001	OUTADJ		NO
25.	SF760001	LEAK	LEAKINT	YES
26.	SF760002	LEAK	LEAKINT	YES
27.	PA720001	NOOPEN		YES
28.	PA750003	ABNORMOP		NO
29.	PA750001	ABNORMOP		NO
30.	PA760001	ABNORMOP	NOMOVE	YES
31.	PA750004	NOOPEN		YES
32.	PA750005	ABNORMOP		NO
33.	PA730001	NOOPEN		YES
34.	PA740001	NOOPEN		YES
35.	PA760002	ABNORMOP	NOMOVE	YES
36.	PA750006	ABNORMOP		NO
37.	PA760003	LEAK	LEAKINT	YES
38.	PA770001	NOOPEN		YES
39.	PA720002	PLUGGED(partial)		NO
40.	PA720004	PLUGGED(partial)		NO
41.	PA720008	PLUGGED(partial)		NO
42.	PA720010	PLUGGED(partial)		NO
43.	PA720012	PLUGGED(partial)		NO
44.	PA720014	PLUGGED(partial)		NO

Table A-3. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
45.	PA720016	PLUGGED(partial)		NO
46.	PA720003	PLUGGED(partial)		NO
47.	PA720005	PLUGGED(partial)		NO
48.	PA720009	PLUGGED(partial)		NO
49.	PA720011	PLUGGED(partial)		NO
50.	PA720013	PLUGGED(partial)		NO
51.	PA720015	PLUGGED(partial)		NO
52.	PA720017	PLUGGED(partial)		NO
53.	PA730004	LEAK(small)		YES
54.	PA760008	ABNORMOP		NO
55.	PA760009	SEIZED		YES
56.	TT780006	??		NO
57.	TT780007	NOOPEN		YES
58.	TT780010	??		NO
59.	SL690006	LEAK(small)		YES
60.	SL710011	LEAK(small)		YES
61.	SL730001	LEAK(small)		YES
62.	SL790002	NOOPEN		YES
63.	SL800002	LEAK	LEAKINT	YES
64.	CR780003	NOCLOSE		YES
65.	CR780004	ABNORMOP	NOMOVE	YES
66.	CR780010	LEAK(small)		YES

Table A-3. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
67.	SG820001	SCORED	NOOPEN	YES
68.	SG760001	LEAK(small)		YES
69.	SG760008	NOHOLD		YES
70.	SG760009	NOHOLD		YES
71.	SG760014	NOHOLD		YES
72.	SG850001	NOOPEN		YES
73.	JY780001	NOOPEN		YES
74.	FF820077	FALSE		NO
75.	JY850004	NOCLOSE		YES
76.	TT780009	??		NO
77.	FF820030	NOHOLD		YES
78.	CR860001	SECLEAK		NO

Table A-4. Motor-operated valve summary

<u>Failure Mode</u>	<u>CREDO Failure Events</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>
Fail to open/close	NOOPEN(22), NOCLOSE(5), NOMOVE(4)	31	17553	
Spurious	NOHOLD(4)	4		1.04E7
Plugged	None	0		1.04E7
Internal leakage	LEAKINT(6)	6		1.04E7
Internal rupture	None	0		1.04E7
External leakage	LEAK(6)	6		1.04E7
External rupture	None	0		1.04E7

Table A-5. Review of pneumatic valve CREDO failures

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
1.	GL690001	NOCLOSE		YES
2.	GL740001	CRACK	PRIMLEAK(small)	YES
3.	SG790034	LEAK(small)		YES
4.	SG810018	LEAK(small)		YES
5.	SG740005	NOCLOSE		YES
6.	SG740006	NOCLOSE		YES
7.	SG740007	NOCLOSE		YES
8.	SG740019	NOCLOSE		YES
9.	SG750010	NOCLOSE		YES
10.	SG850016	DISPLACE		NO
11.	JY790001	NOOPEN		YES
12.	JY800004	OTHER		NO
13.	SC840002	ABNORMOP		NO
14.	SC840003	ABNORMOP		NO
15.	SC840004	ABNORMOP		NO
16.	SC840006	ABNORMOP		NO
17.	SC840007	ABNORMOP		NO
18.	SC840008	ABNORMOP		NO
19.	SC840009	ABNORMOP		NO
20.	SC840011	ABNORMOP		NO
21.	SC840012	ABNORMOP		NO
22.	SC800004	NOCLOSE		YES

Table A-5. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
23.	PA760006	ABNORMOP		NO
24.	PA760007	ABNORMOP		NO
25.	PA730003	??		NO
26.	TT740001	LEAK	LEAKINT(small)	YES
27.	TT750001	NOOPEN		YES
28.	TT750002	NOOPEN		YES
29.	TT780001	ABNORMOP		NO
30.	TT780002	NOHOLD	NOCLOSE	YES
31.	TT750007	NOOPEN		YES
32.	TT750008	NOOPEN		YES
33.	TT750009	NOOPEN		YES
34.	TT750010	NOOPEN		YES
35.	TT750011	NOOPEN		YES
36.	TT740006	NOCLOSE		YES
37.	TT750016	??	NOOPEN	YES
38.	TT750017	NOOPEN		YES
39.	TT750018	??		NO
40.	TT780004	??		NO
41.	TT500019	NOOPEN		YES
42.	TT750020	NOOPEN		YES
43.	TT750021	??		NO
44.	TT780005	??		NO

Table A-5. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
45.	TT750022	??		NO
46.	TT750023	NOOPEN		YES
47.	TT760002	??	NOCLOSE	YES
48.	TT760003	??		NO
49.	TT740007	NOOPEN		YES
50.	TT750024	NOCLOSE		YES
51.	TT760004	??		NO
52.	TT760005	NOOPEN		YES
53.	TT760006	NOOPEN		YES
54.	TT760007	NOOPEN		YES
55.	TT740008	NOCLOSE		YES
56.	TT740009	NOCLOSE		YES
57.	TT740010	NOCLOSE		YES
58.	SC840013	ABNORMOP		NO
59.	SC790005	PRIMLEAK(small)		YES
60.	SC800006	ABNORMOP	NOCLOSE	YES
61.	SC810002	PRIMLEAK(small)		YES
62.	SC780008	LEAKINT		YES
63.	FF800093	ABNORMOP		NO
64.	FF800028	ABNORMOP		NO
65.	JY850009	NOOPEN		YES
66.	ER880020	CRACK(small)		YES

Table A-5. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
67.	SC890001	NOCLOSE		YES
68.	SC890002	NOCLOSE		YES
69.	SC890003	NOCLOSE		YES
70.	ST820001	FRACTURE	NOOPEN	YES
71.	ST850001	NOCON		YES
72.	FF810018	NOCLOSE		YES
73.	FF810035	ABNORMOP		NO
74.	FF790019	NOCLOSE		YES
75.	FF790017	NOCON		YES
76.	FF790016	ABNORMOP	SPURIOUS	YES
77.	FF800033	ABNORMOP		NO
78.	FF800031	ABNORMOP		NO
79.	FF800030	ABNORMOP		NO
80.	FF800029	ABNORMOP		NO
81.	FF800027	ABNORMOP		NO
82.	FF800043	ABNORMOP		NO
83.	SF800001	CRACK(small)		YES
84.	SF810001	DISTORT		NO
85.	SC820002	SPURIOUS		YES
86.	PA720006	PLUGGED(partial)		NO
87.	PA720007	PLUGGED(partial)		NO
88.	PA730002	LEAK(small)		YES

Table A-5. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
89.	PA750007	NOCLOSE		YES
90.	PA750008	NOOPEN		YES
91.	PA760004	ABNORMOP		NO
92.	PA750009	SEIZED		YES
93.	ER770002	CRACK(small)		YES
94.	ER810001	NOOPEN		YES
95.	ER760001	CRACK(small)		YES
96.	ER650004	CRACK(small)		YES
97.	ER690004	CRACK(small)		YES
98.	ERE70000	SECLEAK		NO
99.	ER700006	NOMOVE		YES
100.	ER700007	NOCLOSE		YES
101.	ER710007	SECLEAK		NO
102.	ER720002	NOOPEN		YES
103.	ER720003	NOOPEN		YES
104.	ER720004	SECLEAK		NO
105.	ER730002	NOOPEN		YES
106.	ER740004	SECLEAK		NO
107.	ER740005	SECLEAK		NO
108.	ER740006	NOOPEN		YES
109.	ER750001	NOOPEN		YES
110.	ER760003	SECLEAK		NO

Table A-5. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
111.	ER790003	NOMOVE		YES
112.	ER770006	NOOPEN		YES
113.	ER780003	SECLEAK		NO
114.	ER780004	SECLEAK		NO
115.	ER810007	SECLEAK		NO
116.	ER760004	NOOPEN		YES
117.	ER740014	NOMOVE		YES
118.	ER800018	NOOPEN		YES
119.	ER800019	NOOPEN		YES
120.	ER830018	FAILSHUT		YES
121.	FF820084	NOOPEN		YES
122.	FF820085	NOOPEN		YES
123.	FF810009	NOCON	SPURIOUS	YES
124.	FF810017	ABNORMOP		NO
125.	FF830009	ABNORMOP		NO
126.	SG780001	PRIMLEAK(sma11)		YES

Table A-6. Pneumatic valve summary

<u>Failure Mode</u>	<u>CREDO Failure Events</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>
Fail to open/close	NOOPEN(32), NOCLOSE(22), NOMOVE(3), NOCON(2), SEIZED(1)	60	28344	
Spurious	SPURIOUS(3), FAILSHUT(1)	4		1.50E7
Plugged	None	0		1.50E7
Internal leakage	LEAKINT(2)	2		1.50E7
Internal rupture	None	0		1.50E7
External leakage	PRIMLEAK(4), LEAK(3), CRACK(6)	13		1.50E7
External rupture	None	0		1.50E7

Table A-7. Review of rupture disk CREDO failures

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
1.	ER690003	BREACH		YES
2.	ER690001	CRACK		YES
3.	ER690002	CRACK		YES
4.	ER810006	PRIMLEAK		YES
5.	ER770005	PRIMLEAK		YES
6.	ER830001	PRIMLEAK		YES

Table A-8. Rupture disk summary

<u>Failure Mode</u>	<u>CREDO Failure Events</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>
Fail to open	None	0		7.77E5
Premature opening	BREACH(1), CRACK(2), PRIMLEAK(3)	6		7.77E5

Table A-9. Review of motor-driven pump CREDO failures

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
1.	JY860016	SPURIOUS		YES
2.	ER860014	ABNORMOP		YES
3.	ER650001	SEIZED	NOSTART	YES
4.	ER630002	SPURIOUS		YES
5.	ER650002	SEIZED	NOSTART	YES
6.	ER700003	ABNORMOP		YES
7.	ER700004	ABNORMOP		NO
8.	ER730001	ABNORMOP		YES
9.	ER770003	ABNORMOP		NO
10.	ER800005	SPURIOUS		YES
11.	ER810004	SEIZED	NOSTART	YES
12.	ER820003	PRIMLEAK(sma11)		YES
13.	ER820005	SECLEAK		NO
14.	ER700013	SPURIOUS		NO
15.	ER820002	SPURIOUS		NO
16.	SG790032	LEAK	SECLEAK	NO
17.	SG790033	PLUGGED		NO
18.	SG810023	LEAK	SECLEAK	NO
19.	SG830001	PLUGGED		NO
20.	SG830002	LEAK	SECLEAK	NO
21.	SG830007	NODEENER	NORUN	YES
22.	SG830008	NODEENER	NORUN	YES

Table A-9. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
23.	SG740020	PLUGGED		NO
24.	SG840001	LEAK	SECLEAK	NO
25.	JY770016	ABNORMOP		NO
26.	JY790042	FALSE		NO
27.	JY800021	SPURIOUS		NO
28.	JY860015	NOMOVE	NORUN	YES
29.	ER630001	SEIZED	NOSTART	YES
30.	SL830009	NORUN	Problem not fixed. Count 1 per year.	YES
31.	SL830008	NORUN	"	NO
32.	SL820009	NORUN	"	YES
33.	SL810003	NORUN	"	YES
34.	SL800003	NORUN	"	YES
35.	SL740007	NORUN	"	YES
36.	SL740006	NORUN	"	NO
37.	SL740005	NORUN	"	NO
38.	SL710017	NORUN	"	YES
39.	SL710016	NORUN	"	NO
40.	SL710015	NORUN	"	NO
41.	SL710014	NORUN	"	NO
42.	SL710013	NORUN	"	NO
43.	SL700045	NORUN	"	YES
44.	SL700044	NORUN	"	NO

Table A-9. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
45.	SL700041	NORUN	Problem not fixed. Count 1 per year.	NO
46.	SL700040	NORUN	"	NO
47.	SL700037	NORUN	"	NO
48.	SL700035	NORUN	"	NO
49.	SL700033	NORUN	"	NO
50.	SL700032	NORUN	"	NO
51.	SL700030	NORUN	"	NO
52.	SL690010	NORUN	"	YES
53.	SL730007	NORUN	"	YES
54.	SL700047	NORUN	"	NO
55.	SL700039	NORUN	"	NO
56.	SL700038	NORUN	"	NO
57.	SL700036	NORUN	"	NO
58.	SL700034	NORUN	"	NO
59.	SL700031	NORUN	"	NO
60.	SL690009	NORUN	"	NO
61.	SL690001	ABNORMOP	"	YES
62.	SL690002	ABNORMOP	"	NO
63.	SL690005	ABNORMOP	"	NO
64.	SL690007	ABNORMOP	"	NO
65.	SL690008	ABNORMOP	"	NO
66.	SL700002	ABNORMOP	"	YES

Table A-9. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
67.	SL700005	ABNORMOP	Problem not fixed. Count 1 per year.	NO
68.	SL700006	ABNORMOP	"	NO
69.	SL700015	ABNORMOP	"	NO
70.	SL700016	ABNORMOP	"	NO
71.	SL700029	ABNORMOP	"	NO
72.	SL710003	ABNORMOP	"	YES
73.	SL700004	OTHER	NORUN(operator)	NO
74.	SL710006	OTHER	NORUN(operator)	NO
75.	SL710007	OTHER	NORUN(operator)	NO
76.	SL710012	OTHER	NORUN(operator)	NO
77.	SL720003	OTHER	NORUN(operator)	NO
78.	SL720008	OTHER	NORUN(operator)	NO
79.	SL750002	OTHER	NORUN(operator)	NO
80.	SL820002	OTHER	NORUN(operator)	NO
81.	SL750003	OTHER		NO
82.	SL770001	OTHER		NO
83.	SL820006	OTHER		NO
84.	SL830006	OTHER		NO
85.	SL700007	OTHER		NO
86.	SL700025	OTHER		NO
87.	SL710002	NOSTART		YES
88.	SL750001	OTHER	NORUN	YES

Table A-9. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
89.	SL750004	NOSTART(operator)		NO
90.	SL720007	DISCONN	NORUN	YES
91.	SL720005	OTHER	NORUN	YES
92.	SL820003	NOSTART(breaker)		NO
93.	SL810001	ABNORMOP		YES
94.	SG800006	PLUGGED		NO
95.	SG850008	ABNORMOP	NOSTART	YES
96.	SG780007	NOSTART		YES
97.	SC820006	NORUN		NO
98.	SC820007	NOSTART	NORUN	YES
99.	SC830003	NOSTART		YES
100.	SC830004	NONCONT	NORUN	YES
101.	SC830005	NONCONT	NORUN	YES
102.	SC830006	SPURIOUS		YES
103.	SC840001	NOCON		NO
104.	SC780009	SPURIOUS		YES
105.	ER880016	ABNORMOP		NO

Table A-10. Motor-driven pump summary

<u>Failure Mode</u>	<u>CREDO Failure Events</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>
Fail to start	NOSTART(8)	8	1642	
Fail to run	NORUN(19), SPURIOUS(5), ABNORMOP(7)	31		7.16E5
External leakage	PRIMLEAK(1)	1		7.16E5
External rupture	None	0		7.16E5

Table A-11. Review of EM pump CREDO failures

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
1.	ER850012	NOSTART	NORUN	YES
2.	FF800071	SPURIOUS		YES
3.	FF800072	??	NORUN	YES
4.	FF800073	NOENER		YES
5.	FF800085	??		NO
6.	ER640001	LEAKINT	PRIMLEAK(small)	YES
7.	ER830008	NORUN		NO
8.	ER640003	NORUN		YES
9.	ER790011	SPURIOUS		YES
10.	ER810017	ABNORMOP		YES
11.	ER840050	NORUN		YES
12.	ER800031	ABNORMOP		NO
13.	ER840051	NORUN		YES
14.	ER860010	OTHER		NO
15.	FF800008	OUTADJ	NORUN	YES
16.	FF810037	NORUN		NO
17.	FF820014	NORUN	NOSTART	YES
18.	FF820029	NOENER		NO
19.	FF830011	SPURIOUS		YES
20.	FF840047	PRIMLEAK		YES
21.	SC800001	NORUN		YES
22.	SC800002	DISTORT		NO

Table A-11. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
23.	SC800003	DISTORT		NO
24.	SF820002	NORUN		YES
25.	TT760008	LEAK(small)		YES
26.	CR750011	NOENER		NO
27.	CR750012	SPURIOUS		YES
28.	SL780006	NORUN		YES
29.	SL780005	NORUN		YES
30.	SL770009	NORUN		YES
31.	SL770008	NORUN		YES
32.	SL760011	NORUN		YES
33.	SL700046	NORUN		YES
34.	SL700043	NORUN		YES
35.	SL700042	NORUN		YES
36.	SL700017	PLUGGED		NO
37.	SL730006	PLUGGED	NORUN	YES
38.	GL700001	LEAK(small)		YES
39.	GL820001	LEAK(small)		YES
40.	GP720002	LEAK(small)		YES
41.	GP810001	LEAK(small)		YES
42.	CR760002	ABNORMOP		NO
43.	CR780008	NOHOLD	NORUN	YES
44.	CR790001	ABNORMOP		NO

Table A-11. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
45.	SG770010	ABNORMOP		YES
46.	SG740008	ABNORMOP		NO
47.	SG820002	NOENER		YES
48.	JY820006	SPURIOUS	NOSTART	YES
49.	JY830012	NOHOLD	NOSTART	YES
50.	JY840012	OTHER		NO
51.	SC780003	NOENER(operator)		NO
52.	SC780004	NOENER	NORUN	YES
53.	SC780005	NOENER	NORUN	YES
54.	SC780006	NOENER	NORUN	YES
55.	SC790001	NOSTART		YES
56.	SC790002	NORUN		YES
57.	SC790003	NOENER		NO
58.	SC790004	NOSTART	NORUN	YES
59.	SC800005	OUTADJ	NORUN	YES
60.	SC810001	NORUN		YES
61.	SC790006	NORUN(operator)		NO
62.	SC820003	NONCONT	SPURIOUS	YES
63.	SC820004	NONCONT	NORUN	YES
64.	SC820005	NONCONT	NORUN	YES
65.	SC830002	NORUN		YES
66.	SC800007	NOSTART	NORUN	YES

Table A-11. (continued)

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
67.	FF800070	ABNORMOP		NO
68.	JY850010	NOHOLD	NORUN	YES
69.	JY860010	SPURIOUS		NO
70.	JY780007	NOMOVE		YES
71.	JY790010	NOSTART		YES
72.	JY790011	NOSTART		YES
73.	JY800008	SPURIOUS		NO
74.	JY800009	OTHER	NORUN	YES
75.	JY810003	NOSTART		YES
76.	JY820005	NOHOLD	NORUN	YES
77.	JY830013	SPURIOUS		NO
78.	JY840011	NOMOVE	NORUN	YES
79.	JY860009	NOHOLD	NORUN	YES
80.	JY860011	NOHOLD	NOSTART	YES
81.	FF890026	CRACK	NORUN	YES
82.	FF890027	SHTGND	NORUN	YES
83.	FF890005	NOCON	NORUN	YES
84.	FF890006	NOENER	NORUN	YES
85.	FF890007	SHTGND		NO

Table A-12. EM pump summary

<u>Failure Mode</u>	<u>CREDO Failure Events</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>
Fail to start	NOSTART(8), NOENER(2)	10	3504	
Fail to run	NORUN(38), SPURIOUS(5), ABNORMOP(2)	45		2.43E6
External leakage	PRIMLEAK(2), LEAK(5)	7		2.43E6
External rupture	None	0		2.43E6

Table A-13. Review of IHX heat exchanger CREDO failures

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
1.	ER700001	OTHER		NO
2.	SG830009	PLUGGED(seal gas)		NO
3.	SG850014	PLUGGED(seal gas)		NO

Table A-14. IHX heat exchanger summary

<u>Failure Mode</u>	<u>CREDO Failure Events</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>
All failure modes	None	0		4.97E5

Table A-15. Review of piping CREDO failures

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
1.	SL740004	LEAK(small)		YES
2.	GL770001	LEAK(small)		YES
3.	GL770002	CRACK(small)		YES
4.	SG830016	CRACK(small)		YES
5.	JY790046	OTHER		NO
6.	JY830039	PLUGGED		YES

Table A-16. Piping summary

<u>Failure Mode</u>	<u>CREDO Failure Events</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>
Plugged	PLUGGED(1)	1		1.81E9ft
External leakage	LEAK(2), CRACK(2)	4		1.81E9ft
External rupture	None	0		1.81E9ft

Table A-17. Review of cold trap CREDO failures

<u>No.</u>	<u>Event</u>	<u>Failure Mode</u>	<u>Revised Failure Mode</u>	<u>Include?</u>
1.	ER800030	OTHER		NO
2.	ER820033	OTHER		NO
3.	ER680002	PLUGGED		YES
4.	ER650003	PLUGGED		YES
5.	ER630003	PLUGGED		YES
6.	ER700002	PLUGGED		YES
7.	ER770001	PLUGGED		YES
8.	ER770019	PLUGGED		YES
9.	FF810011	NOENER		NO
10.	FF830048	PLUGGED		NO
11.	FF830067	PLUGGED		NO
12.	FF830049	PLUGGED		NO
13.	SL760003	PLUGGED		YES
14.	CR770001	PLUGGED		YES
15.	SG830015	ABNORMOP		NO
16.	SG850018	ABNORMOP		NO
17.	ER790013	PLUGGED		YES
18.	SC820008	ABNORMOP		NO
19.	SC840015	ABNORMOP		NO

Table A-18. Cold trap summary

<u>Failure Mode</u>	<u>CREDO Failure Events</u>	<u>Failures</u>	<u>Demands</u>	<u>Hours</u>
Failure	None	0		7.73E5
Plugged	PLUGGED(9)	9		7.73E5
External leakage	None	0		7.73E5
External rupture	None	0		7.73E5