HEBER GEOTHERMAL BINARY
DEMONSTRATION PROJECT

UNAVAILABILITY DISTRIBUTIONS
FOR PRINCIPAL PUMPS

April 1982

Prepared for
SAN DIEGO GAS & ELECTRIC COMPANY
San Diego, California
and
U.S. DEPARTMENT OF ENERGY
Under Cooperative Agreement No. DE-FC03-80RA50239

Prepared by
PICKARD, LOWE AND GARRICK, INC.
Irvine, California

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by
Robert J. Mulvihill
Edward B. Cleveland

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EXECUTIVE SUMMARY

The purpose of this study has been to review data sources relevant to the failure rate and mean time to repair for the principal pumps of the Heber geothermal project. Based upon that review the distributions of failure rates, repair times and pump unavailability were established. A total of 16 pumps are represented in this study.

The method used to develop data distributions has been to first review as many sources of pump data as are currently available. This review was followed by a study of the features of the pumps specified for the Heber installation and the effects of operation and the environment on those features as they relate to anticipated failure rates and repair times. From this, determinations were made for mean failure rate and repair time values appropriate to specific Heber pumps. Range factors are then selected and used to establish the expected variability of the data. Failure rates and repair times were then combined to obtain the unavailability distribution of each type of pump.

The result of this work is summarized in the following tabulation. The average hours of annual pump unavailability are shown for each of the 16 different types of pumps. Graphs are presented in the report which show the uncertainty about these mean unavailabilities.

<u>Pump</u>	<u>Average Hours Unavailable Per Year</u>	<u>Average Number of Years Between Disabling Failures</u>
Brine Return	60	1
Canal Water, Brine, Sump and Sump Booster	28	2
Hydrocarbon Condensate and Booster	15	3.7
Main Cooling Water	13	4.2
Hydrocarbon Accumulator, Liquid Recovery and Transfer	3.5	4.2
Makeup Water	2.6	4.2
Oily Water		
Sanitary and Wash Water		
Service Water		
Service Water Cooling		
Utility Water		

The uncertainties expressed by the graphs for Heber main cooling water, service water, canal water, sump pumps, etc., are similar to their counterparts in steam and nuclear plants; but, the uncertainties for the brine and hydrocarbon pumps are relatively larger because they are not well represented in the data sources reviewed.

There is a large number of pumps specified for the Heber plant. The 16 different types in this study represent only the larger ones. Yet, in this group of 16, several appear to be quite similar in size, capacity, motor requirement, etc., or could be made so by slight changes to the output requirements. To the extent that similar pumps, some of their parts, or the motors can be standardized, the need for stocking a variety of spares would be reduced and, consequently, maintenance costs would be less. Repair time might also be reduced.

A draft of this report has been reviewed by Fluor's ATD/RAM group (Reference 9). As a result of their experience with hydrocarbon pumps, the uncertainty range factor has been set as 10 for the failure rate of these pumps.

1. INTRODUCTION AND SUMMARY

This is the second in a series of reports under Task E. The purpose of these reports is to document the development of data distributions for equipment of the Heber project which is represented in the plant availability model. As this data is updated, based on new information, revisions of this report will be issued and the findings will be used in the plant availability model to update the estimate of plant unavailability.

In the unavailability analysis conducted by Pickard, Lowe and Garrick, Inc. (PLG), the unavailability contribution of equipment to the plant unavailability has been assessed based upon availability models of the systems and of the reliability, maintainability, and unavailability data estimates developed by PLG, taking into consideration data provided by Fluor Corporation. Uncertainties in the unavailability of critical items cannot be developed directly from the data sources from which the reliability, availability, and maintainability (RAM) data was derived; however, upper and lower bounds can be estimated for the failure rate and for the time to repair.

In order to derive the upper and lower bounds, supplemental data was required, especially where the data relates to the specific materials and environments appropriate to the Heber plant. This report deals with the process of obtaining the supplemental data and assessing the uncertainties relative to data values. Uncertainty can be expressed as an unavailability probability distribution. The greater the span of the distribution, the more uncertain we are of the true unavailability value.

The analysis described in this report is an ongoing process. A principal objective of this process is the reduction of the uncertainty in the unavailability of equipment through the analysis of data on similar equipment operating in similar environments. Pump procurement specifications issued at the time of this study form the basis for the pumps studied. At the time of this study, procurement specifications had been issued for 16 types of pumps. These pumps are listed in Table 1 along with the procurement specification number. The table lists the number of pumps installed, their percent capacity, the flow rate in gallons per minute, the discharge pressure, the motor horse power, and the operating voltage. The total system flow requirement for the indicated pumping function is also listed.

This study reviewed numerous data sources to establish a base from which distributions of failure rate and repair times are derived. Recent reports and publications on pump design and operation were reviewed to determine the impact of design features and materials on failure rate and repair time. Using this information, along with a certain amount of engineering judgment, failure rate and repair time statistics were developed for the 16 different types of Heber pumps considered in the study. Table 2 lists the resulting: mean failure rates and their equivalent mean time between failures (MTBFs); the failure rate range factors; the mean repair time hours; and the repair time range factors. Pump unavailability distributions were generated from this data.

The distributions resulting from this study are presented in the summary section. First is a tabulation of the means and variances of failure rates and repair times for each of the 16 pump types. Following this are graphs of the distributions of failure rate, repair times and unavailability. Each graph shows the cumulative and probability density functions of the lognormally distributed data.

The effects on plant availability of the pump failure rate and repair time uncertainties derived in this study will be determined later in a separate study through the use of sensitivity analyses using the plant availability model.

TABLE 1. MAJOR HEBER PROJECT PUMPS

Item	Pump Name	Procurement Specification	Quantity Installed & Capacity*	Pump Rating		Motor Rating		System Flow Required
				gpm	psid	hp	voltage	
1	Main Cooling Water	832557-46-29	3 - 50%	71,770	58.0	3,500.0	13,800	143,540 gpm/500 Maximum
2	Hydrocarbon Booster	832557-46-39	4 - 50%	11,560	448.0	4,000.0	13,800	23,120
3	Brine Return	832557-46-50	3 - 50%	10,360	416.0	3,500.0	4,160	20,720
4	Hydrocarbon Condensate	832557-46-38	6 - 25%	8,670	130.0	900.0	4,160	34,680
5	Canal Water	832557-46-26	2 - 100%	4,240	18.0	60.0	480	4,240
6	Makeup Water	832557-46-26	3 - 50%	2,040	37.5	100.0	480	4,080
7	Service Water Cooler	832557-46-26	3 - 50%	1,570	53.0	70.0	480	3,140
8	Service Water	832557-46-26	3 - 50%	1,410	64.0	80.0	480	2,820
9	Hydrocarbon Transfer	832557-46-40	2 -	680	46.0	40.0	480	
10	Hydrocarbon Accumulator	832557-46-40	2 -	660	16.0	20.0	480	
11	Hydrocarbon Liquid Recovery	832557-46-40	2 -	300	73.0		480	
12	Brine Sump	832557-46-32	2 - 100%	100	26.2	3.0	480	100
13	Brine Sump Booster	832557-46-31	2 - 100%	100	222.0	20.0	480	100
14	Utility Water	832557-46-26	2 - 100%	100	47.8	5.0	480	100
15	Sanitary and Wash Water	832557-46-26	1 - 100%	100	49.5	5.0	480	100
16	Oily Water Sump	832557-46-32	1 - 100%	100	4.2	0.5	480	100

*Percentage of total requirement.

Note: Blank spaces in the data represent information not available at PLG.

TABLE 2. PUMP FAILURE RATE, MTBF AND REPAIR TIME

Item	Pump Type	Mean Failure Rate per Million Hours	MTBF		Failure Rate Range Factor $\sqrt{95\text{th}/5\text{th}}$	Mean Repair Time, Hours	Repair Time Range Factor $\sqrt{95\text{th}/5\text{th}}$
			Hours	Years			
1	Brine Return	135	7,410	1.0	20.0	-	-
2	Brine Sump, Brine Sump Booster	54	18,520	2.1	10.0	-	-
3	Hydrocarbon; Accumulator, Condensate, Transfer, Liquid Recovery	30	33,330	3.8	10.0	-	-
4	Other Pumps (100 gpm and larger)	27	37,040	4.2	10.0	-	-
5	Brine Return Hydrocarbon Condensate and Booster Main Cooling Water	-	-	-	4.6	56.0	4.6
6	Other Pumps (100 gpm and larger)	-	-	-	9.8	12.8	9.8

2. FAILURE RATE DATA

2.1 DATA

2.1.1 HEBER AVAILABILITY DATA BOOK (Reference 1)

The mean failure rates used for pumps in the initial availability evaluations of the Heber project are shown in Table 3. This data is based on generic sources, PLG turbine and generator availability studies, and data for equipment in hydrocarbon service obtained from Fluor Power Services, Inc. (FPS). Adjustments for the brine and hydrocarbon environments were made, as appropriate, based upon field experience in salt water and hydrocarbon environments.

2.1.2 NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL (Reference 2)

Pumps of a kind similar to some of the Heber pumps and reported in the GADS data system of the NERC are listed in Table 4.

2.1.3 EPRI REPORT AP-2071 (Reference 3)

All of the pumps listed in the Electric Power Research Institute (EPRI) report on coal-fired fossil power plant equipment are shown in Table 5. The data has been arranged in order of decreasing failure rate. The two groupings reflect the distinct difference between pumps handling abrasive fluids and those handling relatively clean fluids.

2.1.4 REACTOR SAFETY STUDY, WASH-1400 (Reference 4)

Pump and motor data from the Reactor Safety Study (RSS) are shown in Table 6. The pump data from this report relates to the indoor, relatively clean environment of a nuclear power plant. As such, it is probably only applicable to Heber service water and main cooling water pumps.

2.1.5 NUCLEAR PLANT RELIABILITY DATA SYSTEM (Reference 5)

Failure rate data for centrifugal pumps, induction motors, flexible couplings, and motor speed controllers are reported in the annual Nuclear Plant Reliability Data System (NPRDS) report. Data from this report for pumps are shown in Table 7 and for motor in Table 8. The data for the flexible coupling and speed controller are listed in Table 9.

2.1.6 IEEE STD-500-1977 (Reference 6)

A limited amount of induction motor data is listed in this source. That data which is applicable to Heber is listed in Table 10.

2.1.7 PLG PRA DATA BOOK (References 7 and 8)

Pump failure rate data used by PLG in probabilistic risk assessments (PRAs) studies for the Zion, Indian Point, Oconee and Midland nuclear power plants is shown in Table 11.

2.2 DISCUSSION

The approach used here to derive failure data has been to review all of the data sources and select the best mean failure rate and range factor for clean water pumps. A lognormal data distribution has been assumed as represented by a mean and a range factor (ratio of $\sqrt{95/5}$ percentiles). Then using these values as a base, appropriate multipliers were selected for the hydrocarbon, dirty water, and brine pumps based on engineering judgment to derive values of the mean and range factor.

The data listed in Section 2.1 represents a reasonably complete set of pumps operating in power plants. With exception of the Heber data listed in Table 3, none of the data is from pumps operating in hot brine or hydrocarbon environments. Heber pumps which handle clean water such as the main cooling water pumps, service water pumps, etc., and those handling some silt or sand such as the canal water pumps and the oily water sump pumps should exhibit failure rates similar to their counterparts in steam and nuclear power plants. Those pumps operating with brine and hydrocarbon, however, are not well represented in the data sources. If properly designed for the service, these pumps should have similar failure rates. However, historical data from generic sources is not available. Consequently, the uncertainty failure rate is relatively larger than for water pumps. This uncertainty is reflected in the range factor.

A principal source of data is that from the NPRDS. It is collected from a large number of operating plants and is carefully screened. Components are listed separately by generic type and size permitting the derivation of different failure rates depending upon the type of motor/pump/coupling combination.

Component data published by the NERC reflects only those failures which cause a full or partial unit outage. As such, failures of redundant components are not represented in the data. For this reason the data is optimistic when used for component failure rates. Nevertheless, it is informative to the extent that it does not deviate substantially from that of other sources.

The report of failure rates for coal fired fossil power plants prepared by Fluor Power Services and published by the Electric Power Research Institute (AP-2071) contains many pumps. Data is given for failure rate and for total restoration time. The sources for this data are not given. It may be presumed that some of the data came from the NPRDS and North American Electric Reliability Council (NERC) reports.

The data from the Reactor Safety Study, WASH-1400, is based upon a large number of data sources, very few of which are power plant data. Additionally, most of the data is 15 to 20 years old.

The data from the PLG/PRA data book has been developed from generic data sources and from the records of the actual power plants for which the probabilistic risk assessment was performed. The data is valid for clean water pumps operating in relatively clean environments.

Operators of the Magma's East Mesa plant have indicated good service from their brine and hydrocarbon pumps. There seems to be little oxidation of ferrous components in the brine system because the brine is oxygen free. The hydrocarbon pumps have required little maintenance other than lubrication and tightening of packings. A review of maintenance logs was not made, however, to verify these subjective conclusions. When specific pump design information becomes available as the result of vendor bids, a complete survey of user experience will be conducted. PLG will solicit failure rate and maintainability data from the East Mesa and Raft River binary cycle plants relative to the brine and hydrocarbon environments as well as from air separation and refrigeration plants wherein a hydrocarbon fluid is used.

2.3 RESULTS

After careful review of all the data obtained, the data from NPRDS was used as the base case. The data from this source falls within the range of all the other data and is reasonably close to the values currently used in the Availability Data Book (Reference 1).

The tabulation below shows the data used to arrive at the base case failure rate. The failure rate of 21.32 or pumps 100 to 70,000 gpm results from dividing the total number of failures (313) in Table 7 by the total operating hours (14.68 million). Similarly, the induction motor failure rate of 3.97 results from 97 failures divided by 24.42 million operating hours (Table 8). The flex coupling failure rate of 1.95 is from Table 9. The total of 27.24 has been truncated to 27 failures per million hours as the base case, item 1, Table 12. Differences in pump design such as solid couplings and speed controllers contributed so little to the overall failure rate that in order to keep the analysis from becoming overly complicated, no distinction has been made in regard to these design features.

Type Component	Mean Failure Rate Per Million Hours
Pumps 100 to 70,000 gpm	21.32
Induction Motors 480 to 13,800 VAC	3.97
Flex Coupling	<u>1.95</u>
Total	27.24

Table 12, item 1 lists the preceding mean failure rate as the base case for pumps handling clean water. The other three types of pumps; hydrocarbon, dirty water (silt, sand, etc.), and brine solution pumps are related to the base case failure rate by multiplier factors.

Multipliers are used to account for the limited design experience for pumps in these applications. The practice of using multipliers to adjust mean failure rates for environmental and other effects is a common technique. The military specification MIL-STD-217C describes the technique and provides tables of multiplier factors for electronic components. A similar standard does not exist for mechanical components, consequently multipliers must be arrived at through the use of related engineering experience as has been done here.

The range factors shown in Table 12 account for the uncertainty as to the effects of the fluid properties and contamination. The base case range factor of 10 is based on the Reactor Safety Study.

TABLE 3. HEBER FAILURE RATE DATA*

Item	Pump	Mean Failure Rate (failure per million hours)
1	Brine Return Brine Booster Brine Suction Brine Suction Booster	125
2	Hydrocarbon Booster	30
3	Hydrocarbon Condensate Hydrocarbon Liquid Recovery Hydrocarbon Unloading	22.7
4	Main Cooling Water	15

*Heber Availability Data Book (PLG-0160, Revision 3).

TABLE 4. PUMP DATA FROM NERC TEN-YEAR REPORT¹

Item	Pump Type	Code	Unavailability From All Causes ²		
			Average Occurrence Per Year	Outage Hours/Years	Outage Hours Occurrence
1	Circulation Water Pumps	803	0.29 (33.11) ³	9.63	33.57
2	Condensate Pumps	804	0.19 (21.69)	4.38	22.59
3	Service Water Pumps	909	0.01 (1.14)	0.11	9.71

1. North American Electric Reliability Council, Generating Data System, Ten-Year Review 1970-1979 Component Cause Code Report.
2. Data is from fossil fueled steam plants 100-199 MWe covers 3,591 unit years.
3. Numbers in () are occurrence frequency per million calendar hours.

TABLE 5. PUMP DATA FROM EPRI REPORT AP-2071 OCTOBER 1981

Pump Application	Page	Failure Rate Per Million Hours	Average Logistics Time, Hours	Mean Time to Restore** Hours	Total Out of Service Time, Hours
<u>Group 1</u>					
Flue Gas Desulfurization Recycle	2-41	913.0	4.3	11.1	15.4
Limestone Feed	2-67	913.0	4.3	11.1	15.4
Thickener Underflow*	2-102	563.0	4.3	11.6	15.9
Flue Gas Desulfurization Bleed*	2-39	563.0	11.5	11.1	22.6
Ash Sluice	2-7	457.0	0.0	3.3	3.3
Limestone Supply	2-74	433.0	5.0	9.4	14.4
<u>Group 2</u>					
Auxiliary Cooling	2-9	114.0	40.0	43.6	83.6
Flue Gas Desulfurization Return Water	2-43	57.0	5.0	8.4	13.4

*Rubber lined.

**Logistics hours have been deducted.

TABLE 5 (continued)

Pump Application	Page	Failure Rate Per Million Hours	Average Logistics Time, Hours	Mean Time to Restore** Hours	Total Out of Service Time, Hours
Boiler Feed-Water/Turbine	2-14	57.0	0.9	67.5	68.4
Boiler Feed-Water/Motor	2-13	57.0	43.8	60.0	103.8
Ash Pond Clearwell	2-6	40.0	310.0	16.0	326.0
Boiler Circulation	2-12	30.0	1.4	15.4	16.8
Condensate	2-28	23.0	3.4	33.0	36.4
Closed Cooling Water	2-19	23.0	82.0	11.0	93.0
Ash Sluice	2-8	17.0	720.0	8.0	728.0
Circulating Water	2-16	16.0	5.0	44.0	49.0
Limestone Mill Sump*	2-72	11.0	72.0	11.0	83.0
Filtrate Return	2-48	1.5	72.0	40.0	112.0

*Rubber lined.

**Logistics hours have been deducted.

TABLE 6. PUMP DATA FROM THE RSS¹

Item	Component	Failure Rate			
		Mean	5th	95th	Range Factor ²
1	Pump	3.0×10^{-5}	3.0×10^{-6}	3.0×10^{-4}	10
2	Motor	1.0×10^{-5}	3.0×10^{-6}	3.0×10^{-5}	3.16
3	Pump and Motor ³	9.3×10^{-5}	$\frac{\text{Variance}^4}{2.5 \times 10^{-8}}$		4.7

1. Reactor Safety Study, WASH-1400.

2. Range factor equals $\sqrt{95\text{th}/5\text{th}}$.

3. Combined from items 1 and 2 by PLG program DPD.

4. Variance determined by computer code for discretization of lognormal distribution.

TABLE 7. CENTRIFUGAL PUMP DATA FROM 1979 ANNUAL NPRDS REPORT*

Size Range (gpm)	Page	Comparable Heber Pump	Number of Failures	Number of Components	Million Operating Hours	Failure Per Million Operating Hours	Average** Out of Service Hours
Over 50,000	455	Main Cooling Water	64	107	2.93	21.8	372
10,000 - 50,000	454	Hydrocarbon Booster, Brine Return	22	97	2.57	8.56	223
2,500 - 10,000	454	Hydrocarbon Condensate, Canal Water	63	338	2.62	24.0	632
500 - 2,500	453	Makeup Water, Service Water Cooler, Service Water, Hydrocarbon Transfer Hydrocarbon Accumulator	38	160	1.45	26.2	118
Under 500	453	Hydrocarbon Liquid Recovery Brine Sump, Brine Sump Booster, Utility Water, Oily Water Sump, Sanitary and Wash Water	126	367	5.11	24.7	583
		Totals	313		14.68		

*NUREG/CR-1635, September 1980.

**Not necessarily representative of system out of service time.

TABLE 8. INDUCTION MOTOR DATA FROM 1979 ANNUAL NPRDS REPORT¹

Size Range ² Voltage AC	Page	Applicable to Heber Pumps	Number of Failures	Number of Components	Million Operating Hours	Failure Rate Per Million Hours	Average ³ Out of Service Hours
14,000 - 13,000 (13.8k)	428	Main Cooling Water, Hydro- carbon Booster	2	4	0.038	52.6 ⁴	3
5,000 - 3,500 (4.16k)	428	Brine Return, Hydrocarbon Condensate	25	439	6.34	3.9	516
500 - 300 (480)	427	Canal Water, Makeup Water, Service Water Cooler, Service Water, Hydro- carbon Transfer, Hydrocarbon Accumulator, Hydrocarbon Liquid Recovery, Brine Sump, Brine Sump Boost, Utility Water, Oil Water Sump, Sanitary and Wash Water	70	1,394	18.04	3.9	424
		Total	97		24.42		

1. NUREG/CR-1635, September 1980.

2. Voltage in () is that used for Heber pump motors noted.

3. Not necessarily representative of system out of service time.

4. Result of one occurrence at one plant wherein two of four motors failed to start.

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TABLE 9. COMPONENT DATA FROM NPRDS

Component	Page	Used on Heber Pumps	Number of Failures	Number of Components	Million Operating Hours	Failure Rate Per Million Hours	Average Out of Service Hours
Flex Coupling	418	Brine Return, Hydrocarbon Condensate, Service Water, Hydrocarbon Transfer, Hydrocarbon Accumulator, Hydrocarbon Liquid Recovery	3	65	1.535	1.95	160
Proportional Electronic Controller	345	Brine Return	32	516	17.973	1.78	488

TABLE 10. IEEE-STD-500 DATA ELECTRIC MOTOR

Type Motor	Recommended Failure Rate				Data Variability, All Failure Modes		
	All Modes	Fails to Run	Fails to Start	Incipient	Low (5th Percentile)	Recommended (Median)	High (95th Percentile)
AC Polyphase Squirrel Cage Induction (all sizes)	1.293	0.521 (40%)	0.448 (35%)	0.324 (25%)	0.21	1.293	4.889
AC Polyphase Wound-Rotor Induction	2.381	0.952 (40%)	1.191 (50%)	0.238 (10%)	0.6	2.381	8.0

TABLE 11. GENERIC MOTOR-DRIVEN PUMP FAILURE RATE DATA
(From PLG-PRA Data Bank)*

Failure Mode	Failure Rate Per Million Hours					
	Mean	Variance**	5th Percentile	50th Percentile	95th Percentile	Range F $\sqrt{95\%/5\%}$
Fails to Run (data per million operating hours)	26.2	0.0004	7.0	21.0	63.0	3.0
Fails to Start (data per demand)	2,120.0	2.54	56.0	1,700.0	5,100.0	9.5
Combined (one start per year)	26.4					

*Based on data from NPRDS and IEEE-STD-500.

**Variance determined by computer code for discretization of lognormal distribution.

TABLE 12. FAILURE RATE/RANGE FACTOR ADJUSTMENTS

Item	Type of Service	Adjustment of Mean		Adjustment of Uncertainty	
		Multiplier ¹	Failure Rate Per Million Hours	Multiplier ²	Range ³ Factor
1	Clean Water	1.0	27	1.0	10
2	Hydrocarbon	1.1	30	1.0	10
3	Dirty Water	2.0	54	1.0	10
4	Brine Return	5.0	135	2.0	20

1. Increase in frequency of failure due to limited design experience.
2. Increase in range of failure rate due to uncertainty as to fluid properties and contamination under all possible operating conditions.
3. Range factor equals $\sqrt{95\text{th}/5\text{th percentiles}}$.

3. REPAIR TIME DATA

3.1 DATA

3.1.1 HEBER AVAILABILITY ASSESSMENT REPORT (Reference 8)

The Heber Project Availability Data Book used only mean repair time values. These are:

<u>Pump</u>	<u>Mean Repair Time, Hours</u>
Brine Return and Main Cooling Water	24
Other Pumps	30

3.1.2 NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL (Reference 2)

Outage time data from the NERC is shown in Table 4. The data ranges from 9.7 to 33.6 hours and averages 22 hours per occurrence. It is applicable to the extent that it represents outages caused by individual pumps.

3.1.3 NUCLEAR PLANT RELIABILITY DATA SYSTEM (Reference 5)

The repair times reported by the NPRDS are generally so large that they are suspect. As shown in Tables 7 and 8, pump and motor repair times range from 3 to 632 hours for average values and much higher for maximums.

3.1.4 EPRI REPORT AP-2071 (Reference 3)

Table 13 shows the data from the EPRI report ordered by repair time. When arranged this way the effect of size and complexity on repair times is readily apparent. For the large pumps the repair times range from 33 to 67.5 hours and average about 50 hours. Smaller pumps have repair times from 8 to 16 hours with an average of 11 hours.

Although not a part of this study, it is interesting to note that logistics time seems to be independent of pump size. The weighted average logistic times vary from 0.9 to 720 hours. Actual unweighted logistic times range from zero to 1 year.

3.1.5 PLG PRA DATA BOOK (Reference 7)

Maintenance data derived for the Midland plant is shown in Table 14. It has been segregated into large and small pumps to account for the effect of size on repair time. The large and small pumps to account for the effect of size on repair time. The "large" set of pumps has a mean repair time of 117 hours, while the "small" set of pumps averages 31 hours. There is also a much greater uncertainty in the absolute value of repair time of large pumps as indicated by the large variance.

3.2 DISCUSSION

3.2.1 MAINTAINABILITY FACTORS

The average time it takes to restore the lost function following a failure depends upon many factors. Some of the factors that influence restoration time are noted below.

1. Type of failure mode.
2. Size and complexity of the component.
3. Design features.
4. Location and accessibility.
5. Required cooldown/shutdown/startup time.
6. Importance of function to power or safety.
7. Time of day of failure.
8. Onsite or factory repair.
9. Availability of spare parts.
10. Flushing or purging (as for hydrocarbon equipment).

Items 1 to 4 relate to actual repair time. The other items relate to logistics time. These two time elements add up to restoration time the total time from failure to the time the item is back in service. Only repair time is considered here. Logistic time depends upon plant layout and the maintenance philosophy and will be determined on an individual component basis in the availability model.

3.2.2 EFFECTS OF SIZE AND COMPLEXITY

The data indicates, as expected, that large pumps take longer to repair than do smaller, less complex ones. Large pumps tend to have more peripheral or support systems and equipment. The 3,500 hp brine return pump for example requires a lube oil and a seal water system, and a motor space heater. These peripheral systems make it more difficult to get at and repair the pump. Also in large pumps the major components are heavy and require special handling equipment. All of this affects repair time and must ultimately be reflected in the data.

3.2.3 EFFECTS OF DESIGN FEATURES

Features which make it easier to remove and disassemble a pump such as through bolts at casing joints and shaft release collars at the impeller will serve to reduce maintenance time. Hardened steel shaft sleeves at packings will permit a tighter packing with less sleeve wear. Rubber liners should be relatively thick and bolted in place, not glued. Where possible, pump parts should be made interchangeable.

3.2.4 EFFECTS OF LOCATION AND ACCESSIBILITY

At the time of this study, a plant layout had not been completed. Consequently, the effects of pump location and accessibility could not be accounted for in the repair time distributions. It is anticipated that pumps will be located with maintainability as an objective. When the plant layout is available, the repair time distributions derived here will be reviewed for possible change.

3.2.5 EFFECT OF HYDROCARBON

Maintenance actions requiring that a hydrocarbon system be opened will require additional time for purging with nitrogen. It is anticipated that this may take up to 1 hour. Actually this would only be required for pump failure modes which require opening the pump casing or the inlet/outlet lines. The frequent pump maintenance actions will tighten packings and lubricate bearings. This will not require nitrogen purging. Consequently, when averaged over all failure modes and maintenance actions, the 1 hour that is required for nitrogen purging will contribute little to the overall repair time hour distribution. This will be examined again when more specific pumps maintenance information becomes available.

3.2.6 EFFECTS OF ENVIRONMENT

The desert environment could have an impact on the repair time of these pumps. Unless shade is provided, metal surfaces may become too hot to touch during the summer. Also, working out of doors in the summer will lower the efficiency of maintenance personnel thus extending the time of any repair. High winds and blowing sand could be another obstacle to efficient repair.

No adjustment to the data has been made to account for these environmental effects. There are preventive measures which can be taken. Temporary shade and windshields can be provided and water spray could be used to cool metal surfaces. It is expected that this sort of thing will be done.

3.3 RESULTS

The repair time data from the data sources discussed previously are summarized in Table 15. The derived repair times are based upon that data and on intervals of hours, shifts, days, etc. For this study, the hydrocarbon booster, brine return, hydrocarbon condensate and main cooling water pumps have been classified as "large." All others are "small." Repair times for large pumps range from 9.7 to 117 hours (from one shift to 5 days). For large pumps, the minimum (5th percentile) is set at 8 hours or one shift. The maximum (95th percentile) is set at 7 days or 168 hours (three 8-hour shifts per day are assumed). When fitted to a lognormal distribution this results in the following:

Mean:	56 hours
Median:	38.4 hours
Variance:	30×10^2 hours
Range Factor:	4.6

For small pumps, the average repair time is from 8 to 16 hours or between one and two 8-hour shifts. For small pumps the choice is 1 half-hour minimum and 2 days (48 hours) maximum for lognormal values of:

Mean: 12.8 hours

Median: 5 hours

Variance: 86 hours

Range Factor: 9.8

These results are shown in Table 16.

TABLE 13. PUMP RESTORATION TIME DATA FROM EPRI REPORT AP-2071

Pump Application	Page	Mean Time to Repair, Hours	Average Logistics Time, Hours	Mean Time to Restore, Hours
<u>Group 1</u>				
Boiler Feed/Turbine	2-4	67.5	0.9	68.4
Boiler Feed/Motor	2-13	60.0	43.8	103.8
Auxiliary Cooling	2-9	43.6	40.0	83.6
Circulating Water	2-16	44.0	5.0	49.0
Condensate	2-28	33.0	3.4	36.4
<u>Group 2</u>				
Ash Pond Clearwell	2-6	16.0	310.0	326.0
Boiler Circulation	2-12	15.4	1.4	16.8
Thickener Underflow	2-102	11.6	4.3	15.9
Flue Gas Desulfurization Recycle	2-41	11.1	4.3	15.4
Limestone Feed	2-67	11.1	4.3	15.4
Flue Gas Desulfurization Bleed	2-39	11.1	11.5	22.6
Closed Cooling Water	2-19	11.0	82.0	93.0
Limestone Mill Sump	2-72	11.0	72.0	83.0
Limestone Supply	2-74	9.4	5.0	14.4
Flue Gas Desulfurization Return Water	2-43	8.4	5.0	13.4
Ash Sluice Water	2-8	8.0	720.0	728.0

TABLE 14. PLG PRA DATA

Pump Application	Mean Maintenance Time, Hours	Variance of Maintenance Time, Hours
<u>Large</u>		
Service Water	117.0	15,200.0
Component Cooling Water	117.0	15,200.0
Safeguards Chilled Water	117.0	15,200.0
<u>Small</u>		
Decay Heat Removal	20.9	28.0
Auxiliary Feedwater/ Turbine	20.9	28.0
Auxiliary Feedwater/ Motor	20.9	28.0
Reactor Building Spray Pump	20.9	28.0
Air Cooling Unit Booster	20.9	28.0
High Pressure Injection Makeup	40.8	27.0
Air Cooling Unit Pump	40.8	27.0

TABLE 15. SUMMARY OF PUMP REPAIR TIME DATA

Data Source	Pump Type	Repair Time, Hours			Mean	Variance*
		Minimum	Average	Maximum		
Heber Data Book	Brine Return and Main Cooling Water	--	24	--	--	--
	Others	--	30	--	--	--
EPRI Fossil	Large	33.0	50	67.5	--	--
	Small	8.0	11	16.0	--	--
NERC	Large	9.7	22	33.6	--	--
PLG PRA Data	Large	--	--	--	117	15×10^3
	Others	--	--	--	31	27.5

*Variance determined by computer code for discretization of lognormal distribution.

4. CONCLUSIONS

The purpose of this study has been to derive distributions of failure rate and repair time for the Heber pumps which are controlled by procurement specifications to obtain a measure of uncertainty in pump unavailability. A large number of data sources have been reviewed. Very little data is from pumps operating in a geothermal environment. Nevertheless, it has been possible to derive distributions which are based on power plant pump data, and, where appropriate, have been factored to account for operation in the geothermal environment.

Table 16 lists the means and variances of the failure rates and repair time lognormal distributions derived for 16 different Heber pumps. Figures 1 through 4 are lognormal plots of the failure rate distributions for the four major classifications of pumps: clean water, hydrocarbon, dirty water, and brine solution.

Figures 5 and 6 are lognormal plots of the repair time distributions for the two classifications; large and small pumps. The mean repair times are 56 hours and 12.8 hours.

The repair times derived here do not include logistics time such as waiting for spare parts, tools, etc., or administrative and delays awaiting assignment of maintenance personnel. However, it is expected that these effects will have a minimum effect on restoration time. Efforts will be made to define spare requirements so that delays will not occur. Currently SDG&E anticipates having only a standard day shift maintenance crew for 5 days per week. But personnel will be on call for off shift periods and can be at the plant within 1 hour. The effect will be only a slightly longer restoration time for major failures which are expected to have very low frequencies of occurrence. This should already be taken into account by virtue of the generous range factors selected for the repair times.

The unavailability of individual pumps has been calculated from the failure rates and repair times derived here. The mean unavailability values are listed in Table 16 as fractional time and as unavailability hours per calendar year. Figures 7 through 12 are unavailability plots for six classes of pumps. The resulting range factors are relatively large and there is a need to reduce the uncertainty. In the future, all available data will be collected on pumps in brine and hydrocarbon environments. The objective in obtaining this data will be to reduce the uncertainty where justified. Mean values of the failure rate and mean time to repair in the Availability Data Book (Reference 1) will be adjusted in the next revision based on the results of this study and future data received before the revision of Reference 1.

During the course of this study, some thought was given to the possibility of standardizing some of the pumps. It was concluded that at this point in time that when procurement specifications have already been released for bids, it is probably too late to standardize pumps and

motors. However, if during the bid evaluation and subsequent discussions with bidders, some degree of standardization is possible, this might serve to reduce the number of spare parts required and also lead to a reduction in repair time.

The method of deriving failure rate and repair time distributions using applicable historical data and judgment factors has been used as a substitute for an equipment test program. The distributions in this report are believed to be sufficiently representative of the actual equipment performance when used in the availability model to identify critical items. Further refinements will be made in the data as additional information is obtained. Data is being requested on the operation of petrochemical hydrocarbon pumps and operating data is to be requested from the East Mesa and Raft River plants. As bidders supply detailed proposal information on pump design features and materials their effects on pump availability will be evaluated. When all of this information has been received and evaluated, it is expected that some of the uncertainties reflected in the present distribution can be reduced. At that time, this report will be revised and reissued.

TABLE 16. DERIVED HEBER PUMP DATA

Item	Heber Pump	Failure Rate ¹		Repair Time ²		Mean Unavailability	Unavailability Hours Per Calendar Year
		Mean	Variance ³	Mean Hours	Variance ³		
1	Brine Return Pump	135	4.0×10^{-7}	56.0	3×10^3	0.0069	60.0
2	Brine Sump Pump	54	1.9×10^{-8}	12.8	86	0.0032	28.0
3	Brine Sump Booster	54	1.9×10^{-8}	12.8	86	0.0032	28.0
4	Canal Water Pump	54	1.9×10^{-8}	12.8	86	0.0032	28.0
5	Hydrocarbon Condensate Pump	30	5.1×10^{-9}	56.0	3×10^3	0.0017	15.0
6	Hydrocarbon Booster Pump	30	5.1×10^{-9}	56.0	3×10^3	0.0017	15.0
7	Hydrocarbon Accumulator Pump	30	5.1×10^{-9}	12.8	86	0.0004	3.5
8	Hydrocarbon Liquid Recovery	30	5.1×10^{-9}	12.8	86	0.0004	3.5
9	Hydrocarbon Transfer Pump	30	5.1×10^{-9}	12.8	86	0.0004	3.5
10	Main Cooling Water	27	4.0×10^{-9}	56.0	3×10^3	0.0015	13.0
11	Makeup Water Pump	27	4.0×10^{-9}	12.8	86	0.0003	2.6
12	Oily Water Sump	27	4.0×10^{-9}	12.8	86	0.0003	2.6

1. Failure rate per million hours.

2. Does not include logistics time.

3. Variance determined by computer code for discretization of lognormal distribution.

TABLE 16 (continued)

Item	Heber Pump	Failure Rate ¹		Repair Time ²		Mean Unavailability	Unavailability Hours Per Calendar Year
		Mean	Variance ³	Mean Hours	Variance ³		
13	Sanitary and Wash Water Pump	27	4.0×10^{-9}	12.8	86	0.0003	2.6
14	Service Water Pump	27	4.0×10^{-9}	12.8	86	0.0003	2.6
15	Service Water Cooling Pump	27	4.0×10^{-9}	12.8	86	0.0003	2.6
16	Utility Water Pump	27	4.0×10^{-9}	12.8	86	0.0003	2.6

1. Failure rate per million hours.

2. Does not include logistics time.

3. Variance determined by computer code for discretization of lognormal distribution.

FIGURE 1. CLEAN WATER PUMPS FAILURE DISTRIBUTION

FIGURE 2. HYDROCARBON PUMPS FAILURE DISTRIBUTION

FIGURE 3. DIRTY WATER PUMPS FAILURE DISTRIBUTION

FIGURE 4. BRINE SOLUTION PUMPS FAILURE DISTRIBUTION

FIGURE 5. LARGE PUMPS REPAIR TIME DISTRIBUTION

FIGURE 6. SMALL PUMPS REPAIR TIME DISTRIBUTION

FIGURE 7. BRINE RETURN PUMP UNAVAILABILITY DISTRIBUTION

FIGURE 8. BRINE SUMPS AND CANAL WATER PUMPS UNAVAILABILITY DISTRIBUTION

FIGURE 9. HYDROCARBON CONDENSATE AND BOOSTER PUMPS UNAVAILABILITY DISTRIBUTION

FIGURE 10. HYDROCARBON ACCUMULATOR, LIQUID RECOVERY, AND TRANSFER PUMPS UNAVAILABILITY DISTRIBUTION

FIGURE 11. MAIN COOLING WATER PUMP UNAVAILABILITY DISTRIBUTION

FIGURE 12. OTHER PUMPS (100 GPM AND LARGER) UNAVAILABILITY DISTRIBUTION

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