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HEBER GEOTHERMAL BINARY DEMONSTRATION PROJECT.

FINAL DESIGN AVAILABILITY ASSESSMENT

by

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1. EXECUTIVE SUMMARY

The final availability assessment was carried out based on the "approved for design" issue of piping and instrumentation diagrams (P&ID), the finalized process flow diagrams, and system descriptions. The system availability models and the plant availability model were updated and point estimates of system equivalent availability and plant availability were generated. Availability values were compared to their availability targets established in the availability data book, April 1981 (Reference 1) and updated in Revision 3 of the availability data book, January 1982 (Reference 2). All systems exceeded the target with the exception of the hydrocarbon system, hydrocarbon loading and unloading system, and cooling water system (only slightly below target value). A comparison of system and plant assessed and target equivalent availabilities is presented in Table 1. The plant assessed equivalent availability, not including planned maintenance outages, is 0.9033, equivalent to 35.3 days per year of forced and deferred corrective maintenance outages. Including 30 outage days per year for planned maintenance, the assessed equivalent availability is 0.8211, equivalent to 65.3 days per year of outages.

The plant availability assessment of the "approved for design" issue of drawings was carried out based on a 91 state Markov model. The model structure and input data were based on system/subsystem assessments that were conducted using the Electric Power Research Institute (EPRI) GO methodology and availability block diagram models.

The systems and major equipment were ranked based on their contribution to unavailability. This ranking was used to update the availability critical items list (ACIL) presented in Table 2. The recommendations list contains a running list of Pickard, Lowe and Garrick, Inc. (PLG), availability enhancement recommendations that were developed as the design progressed. It has been augmented to include recommendations pertinent to the final design. This list is presented in Table 3.

Spare parts quantities were developed for items on the ACIL based on a restocking period of 12 months and a 95% confidence level of not running out. The list is presented in Section 5.4.

TABLE 1. SYSTEM UNAVAILABILITY RANKING AND AVAILABILITY TARGETS

Assessed Unavailability Ranking	System	Target Availability	Assessed Availability*	Assessed Unavailability (hours/year)	Components Contributing To Criticality
1	Turbine-Generator	0.93	0.9533	409	Turbine-Generator
2	Hydrocarbon System	0.985	0.9745	223	Valve Leakage, Condensers, and Pumps
3	Brine Heat Exchange and Return	0.976	0.9803	175	Heat Exchangers, Pumps, and Valve Leakage
4	Hydrocarbon Unloading and Recovery	0.997	0.9906	82	Valve Leakage, Condenser, Compressor, Pumps
5	Brine Supply (not FPS responsibility)	0.985	0.9928	63	Hot Brine (downhole pumps)
6	Cooling Water	0.998	0.99634	32	Pumps, Valves
7	Electrical Distribution	0.995	0.99727	24	Main and Service Transformers
8	Instrumentation and Control	0.999	0.999	9	
9	Service Water	0.995	0.99997	0.2	
10	Plant and Instrument Air	0.995	0.99997	0.2	
11	Hydrocarbon Relief and Flare	0.995	≈ 1.0	≈ 0	
12	Inert Gas	0.999	≈ 1.0	≈ 0	

*The nine numerals after the decimal point do not represent significant figures. They are used to locate the decimal point; i.e., they are the complement of zero numerals in the complementary unavailability value.

TABLE 2. AVAILABILITY CRITICAL ITEMS LIST

Criticality Ranking	Component or Component Group	Failure Mode	MTBF	MTTR (hours)	Equivalent Unavailability (hours/year)	Basis for Criticality Ranking	Corrective Action
1	Turbine (excluding scheduled outage time)	Fail to Function	5,286 hours	220	Approximately 350	Historical evidence from industry data sources and preliminary vendor data give the basis for the assessment.	An ongoing availability improvement program is recommended after the selection of the supplier is made.
2	Hydrocarbon System Valves	External Leakage/Fail to Function	2,130 Hours	32	130 for All Valves	Cumulative effect of external leakage from all of the valves in the hydrocarbon system.	
3	Brine/Hydrocarbon Heat Exchangers	Internal Leakage	25,000 Hours Per Exchanger	85	77 for All Exchangers	The present configuration has two parallel strings of four exchangers each.	
4	Brine Return Pumps	Fail to Function	7,400	56	65 for All Pumps	The present configuration has four nominal 25% capacity pumps. No redundancy.	Select pump characteristics and motor size such that upon loss of a pump, remaining three operating pumps will increase capacity to approximately 33 1/3% each.
5	Condensers	Internal Leakage	30,000 Hours 3.42 Years	110	64 for All Condensers	The assessed configuration has a dual turbine outlet to two condensers.	It is recommended that provision for blind flanges be added to permit isolation of individual condensers. This would afford a definite increase in availability.
6	Generator/Exciter	Fail to Function	3.35 Years	200	Approximately 59	Same as item 1.	Same as item 1.
7	Hydrocarbon Unloading and Recovery System Valves	External Leakage	5,000 Hours	32	56 for All Valves	The system assessment sums the cumulative effect of all valves in this system.	
8	Hot Brine Well Pumps	Fail to Function	2,000 Hours Per Pump	48	43 for All Pumps	Limited operating data from EPRI geothermal contractors indicate that downhole brine pumps have design problems accounting for currently high unavailability. Unavailability based on 17 of 18 wells for 100% output.	Even though the current experience indicates a low MTBF, a downhole hydraulic turbine pump being developed by J. Hilbert Anderson, Inc. and Worthington Pump Corp., shows considerable promise of achieving MTBF values of 1 year or greater. Meanwhile, sufficient redundancy to meet the MTBF requirements is recommended.

TABLE 2 (continued)

Criticality Ranking	Component or Component Group	Failure Mode	MTBF	MTTR (hours)	Equivalent Unavailability (hours/year)	Basis for Criticality Ranking	Corrective Action
9	Brine Heat Exchange and Return System Valves	External Leakage/ Fail to Function	8,000 Hours	31	34 for All Valves	The cumulative effect of external leakage of all system valves provides the criticality basis.	
10	Cold Brine Injection Well Pumps	Fail to Function	2,000 Hours	48	20	Same as item 8. Unavailability based on eight of nine wells for 100% capacity.	
11	Condensate Pumps	Fail to Function	33,333 Hours	56	15	Present configuration has four 25% capacity pumps. No redundancy.	
12	Booster Pumps	Fail to Function	33,333 Hours	56	15	Same as item 11.	
13	Main Cooling Water Pumps	Fail to Function	37,000 Hours	12.8	13	Present configuration has two 50% capacity pumps. No redundancy.	
14	Storage Tank Cooler	Leakage	30,300 Hours	71	11	Present configuration has only one storage tank cooling loop.	

TABLE 3. CHRONOLOGICAL RECOMMENDATIONS LIST - HEBER AVAILABILITY ENHANCEMENT PROGRAM

Sheet 1 of 4

Item	Description	Recommendation Date	Reference	Disposition
1	Consideration of adding redundant service and/or main transformer.	May 1981	Preliminary Cost-Benefit Analysis of Heber Substation Alternate Configurations, PLG-0174.	Subsequent detailed availability and cost-benefit analysis showed only a marginal improvement. Recommendation withdrawn by PLG.
2	Consideration of isolation of pairs of brine/hydrocarbon heat exchangers by use of appropriate isolation valves with isolation of each train as the minimum implementation.	May 1981	Preliminary Cost-Benefit Analysis of Heber/Brine Hydrocarbon Heat Exchanger Alternate Configurations, PLG-0173.	The design configuration has been changed by FPS to include valves which permit each train to be isolated. Additional recommendations are provided in item 6.
3	Consideration of condenser isolation and crossover valves for either the two-condenser or four-condenser configurations.	May 1981	Preliminary Cost-Benefit Analysis of Heber Condenser Alternate Configurations, PLG-0172.	Four-condenser configuration has been deleted due to cost considerations. Need for crossover valve has been eliminated by combined turbine exhaust design. Isolation valve recommendation is covered in item 8.
4	Retention of design guide cooling tower system concept as the basis for design and engineering.	May 1981	Preliminary Cost-Benefit Analysis and Heber Cooling Tower Alternate Configurations, PLG-0177.	FPS has retained the original Design Guide concept.
5	Delete one of the three instrument air compressor trains.	June 1981	Cost-Benefit Analysis of Service and Instrument Air Alternate Configurations.	The diesel-powered air compressor train has been deleted.
6	Placement of isolation valves before and after heat exchanger with a bypass line containing a valve to permit isolation of individual heat exchangers.	October 19, 1981	PLG letter to FPS.	Train isolation valves are present in current design. Individual heat exchanger isolation valves have not been included by FPS due to concern about potential brine return temperature control problems.
7	Manifolding instrumentation tapoffs for the brine and hydrocarbon piping to reduce potential leakage.	October 19, 1981	PLG letter to FPS.	FPS is implementing this recommendation in the next issue of P&IDs. See item 16 for further comments.

TABLE 3 (continued)

Sheet 2 of 4

Item	Description	Recommendation Date	Reference	Disposition
8	Provide condenser isolation valve dual exhaust.	October 19, 1981	PLG letter to FPS.	FPS has implemented recommendation by including condenser isolation valves. Turbine suppliers have confirmed that turbine thrust imbalance resulting from one condenser operating can be tolerated, eliminating the need for combined exhaust. Revision D drawing shows crossover line with crossover valve from turbine exhausts.
9	Bypass around knockout drum level control valve.	October 19, 1981	PLG letter to FPS.	FPS has implemented recommendation by providing bypass with manual control valve.
10	Placing check valve after manifold bypass from hydrocarbon booster pump.	October 19, 1981	PLG letter to FPS.	FPS has implemented recommendation.
11	Substation unit design base case Sketch E-100, Revision A be used for continued design development.	November 17, 1981	PLG letter to Richard F. Allen (SDG&E).	FPS is using Sketch E-100, Revision A as the basis for design.
12	Eliminate requirement for individual analog-to-digital (A/D) converters for noncritical control points for instrumentation and control and data acquisition systems. For critical control points, single A/D converter backed up by a redundant A/D converter should be permitted.	January 4, 1982	PLG letter to Richard F. Allen (SDG&E).	FPS is incorporating the recommendation into the central control specification.

TABLE 3 (continued)

Sheet 3 of 4

Item	Description	Recommendation Date	Reference	Disposition
13	Permit a distributed programmable controller system as an alternate to the one operational, one backup requirement.	January 4, 1982	PLG letter to Richard F. Allen (SDG&E).	FPS will accept a distributed programmable controller system if proposed by supplier.
14	Give consideration to eliminating backup manual control with analog type display station. Train the operators on a dummy data base so that digital systems backup capability can be relied on.	December 1981	Instrumentation and control system study PLG-0214.	FPS is currently requiring the backup manual controls in the central control specification.
15	Placement of isolation valves before and after heat exchanger and a bypass line containing a valve to permit isolation of individual heat exchangers.	March 2, 1982	PLG letter to R. S. Chana (FPS) - review of Revision D drawings.	See item 6.
16	Manifolding of instrumentation tapoffs for the hydrocarbon piping and providing a single isolation valve to reduce potential leakage.	March 2, 1982	PLG letter to R. S. Chana (FPS) - review of Revision D drawings.	Revision D drawing does not contain these changes. The "approval for design" issue shows a high degree of manifolding.
17	Provide a combined turbine exhaust arrangement.	March 19, 1982	Review of Revision D drawings.	Revision D drawing shows a turbine crossover line containing a valve between the two turbine exhausts. Implementation of combined exhaust as part of turbine or removal of crossover valve will eliminate potential turbine thrust imbalance problems. See item 19 for further comments.
18	Install the spare brine return pump when 100% brine flow plant capacity is achieved.	March 19, 1982	New recommendation based on March 3, 1982, PLG letter to R. S. Chana (FPS) and February 1982 PLG Report PLG-0221, Unavailability Distributions for Principal Pumps.	SDG&E has asked FPS to eliminate this pump but leave space for future installation in February 24, 1982, letter from R. F. Allen to R. S. Chana.

TABLE 3 (continued)

Sheet 4 of 4

Item	Description	Recommendation Date	Reference	Disposition
19	Provide for blind flanges on inlet and outlet of each condenser so that during extended condenser maintenance, plant can run at 50% capacity.	December 30, 1982	Telephone conversation with R. S. Chana (FPS).	Turbine exhaust crossover valve and condenser inlet valves have been eliminated in the "approved for design" P&ID due to excessive cost for 72-inch valves. FPS to consider blind flanges or spool piece containing blanks.
20	Select brine return pump characteristics such that on loss of one of four pumps, the remaining three deliver flow at a greater rate than the nominal rating. Size motors accordingly.	December 30, 1982	Telephone conversation with R. S. Chana (FPS).	May be possible depending on suction and discharge head versus flow characteristics. FPS has been discussing this matter with Chevron Resources for 2 weeks.

2. SUMMARY

An availability assessment of the principal systems of the Heber Geothermal Power Plant has been carried out based on the final issue of the process descriptions, process flow diagrams, and the "approved for design" P&IDs prepared by Fluor Power Services, Inc. (FPS). The principal systems are those which contribute most to plant unavailability.

The plant equivalent availability, considering forced and deferred corrective maintenance outages, was computed using a 91 state Markov model to represent the 29 principal system failure configurations and their significant combinations. The failure configurations and associated failure and repair rates were defined from system/subsystem availability assessments that were conducted using the availability assessments based on the EPRI "GO" methodology and availability block diagram models.

The availability and unavailability ranking of the systems and major equipment is presented in Table 1. This ranking was used to develop the ACIL presented in Table 2 and the recommendations list in Table 3.

2.1 BRINE HEAT EXCHANGE AND RETURN SYSTEM

The target availability for the brine heat exchange and return system which includes the heat exchangers is 0.976. The "approved for design" assessed equivalent availability is 0.9803 which exceeds the target availability. This availability assessment takes into consideration the equivalent availability contribution of the heat exchanger configuration operating at 50% capacity when one string is isolated for repair. The system design includes blind flanges for isolating an individual string of heat exchangers.

The pump configuration was assessed considering four pumps, each operating at 25% capacity. Failure of a pump reduces the operating capacity of the system to 75% and contributes to unavailability. This approach is conservative because if each of the three unfailed pumps are capable of more than 25% output, the system equivalent availability will be greater than the system assessed equivalent availability quoted above.

2.2 HYDROCARBON SYSTEM

The target availability of the hydrocarbon system including the condensers is 0.985. This target has been lowered once from the original target availability of 0.995 to its present value due to the recognition that additional valves would be required to implement the conceptual design. The "approved for design" equivalent availability assessment is 0.9745 which is lower than the target availability but greater than the initial definitive design availability assessment of 0.9670 (Reference 3).

The increase in system availability is the cumulative effect of: (1) a better data base constructed for the specific materials used in the condensers because condensers are a leading contributor; and (2) reduction of the number of valves directly connected to the main hydrocarbon piping by use of blind flanges and manifolding. These two effects led to an overall increase in availability which was significantly greater than the decrease in availability caused by the elimination of the spare condensate and condensate booster pumps.

The leading contributor to system unavailability is still valve failure to operate and valve leakage failure.

2.3 COOLING WATER SYSTEM

The cooling water system target availability is 0.998. The "approved for design" assessed equivalent availability is 0.99638 which is slightly lower than the target value. The leading contributors to system unavailability are the main cooling water pumps. The pump configuration was assessed as two 50% capacity pumps with no redundancy. If the pumps can operate at greater than 50% design capacity in the event of failure of one pump, a higher system equivalent availability can be achieved.

The contribution of valves to unavailability is also conservative because the data for large valves of the type used in this application exhibit large mean time to repair values. If valve repair could be deferred to nonoperating periods, this would also increase system availability.

2.4 SERVICE WATER SYSTEM

The target availability of the service water system is 0.995. The "approved for design" assessed equivalent availability is 0.99997, which is greater than the target value. The system consists of two strings of pumps and service water coolers, of which only one is needed for the normal cooling loads of the plant. This high availability is attributed to the 100% redundant capacity of the system.

2.5 ELECTRICAL DISTRIBUTION

The target availability of the electrical distribution is 0.995. The "approved for design" assessed equivalent availability is 0.99727, which is greater than the target value. The main and service transformers are the leading contributors to unavailability of this system. These two components are single point failures.

2.6 HYDROCARBON UNLOADING AND RECOVERY SYSTEM

The target availability of this system is 0.997. The "approved for design" assessed equivalent availability is 0.9906, which is less than the target availability.

In analyzing this system we divide the system into five separate function areas listed below:

1. Vapor Recovery
2. Liquid Recovery
3. Unloading
4. Storage Tank and Cooling
5. Transfer to Condensers

We have applied a use factor of 5 days per year for the first three functions and a 50% use factor for the last two functions. The last two functions, storage tank cooling and transfer to condensers, are single train, nonredundant design and contribute most to system unavailability. There is a considerable amount of uncertainty in these assessed unavailability values. Since these two functions are "on demand" functions, there is uncertainty regarding the demand for each one of these functions as well as uncertainty in the impact of failure.

3. INTRODUCTION

This report contains the final availability assessment of the Heber binary cycle geothermal power plant based on the final system descriptions and the "approved for design" piping and instrumentation drawings prepared by FPS, the architect-engineer. This deliverable is the last in Phase 1 of the availability enhancement program. Phase 2 will involve the review of operations and maintenance procedures (Task L) and the development of an availability data collection system (Task M).

The Heber Geothermal Power Plant at Heber, Imperial County, California, will produce 70 MW gross (45 MW net) power from brine having a temperature of 360°F utilizing a binary cycle. The hydrocarbon working fluid is a 90/10 mol percent mixture of isobutane and isopentane. The Heber power plant will be operated by the San Diego Gas & Electric Company (SDG&E). The project is supported by EPRI and the U.S. Department of Energy. The availability enhancement services provided by PLG are performed for SDG&E.

The Phase 1 availability enhancement program consists of the following tasks, culminating in this final design assessment document:

- Task A - Review and Analyze Conceptual Design. This effort required review of the Holt/Procon study (Reference 4) and the Fluor Power Services study (Reference 5) to identify key plant systems and design parameters from an availability viewpoint.
- Task B - Receive and Review Availability Data. Development of the reliability and maintainability data base was the key output of this task. Coordination with the architect-engineer (FPS) was required to review availability data utilized by FPS on similar equipment and to obtain FPS comments on the overall data base.
- Task C - Perform Availability Analyses Based on Conceptual Design. This task involved the development of a plant availability model; failure mode, effects, and criticality analysis (FMECA); plant and system availability targets; and the preliminary ACIL. These were published in the availability data book (References 1 and 2). The systems and plant conceptual design availability assessments were published in References 6 and 7.
- Task D - Options for Increasing Conceptual Design Availability. The principal output of this task was the definition of candidate availability improvement options primarily related to design configurations and specifications. These covered the turbine-generator, brine/hydrocarbon heat exchanger configuration alternatives, hydrocarbon condenser configuration alternatives, substation and transformer configurations, number and configuration of air compressors, process control configurations (distributed digital and analog systems), and the number and configuration of cooling towers. Results of these studies are published in References 8 through 12.

- Task E - Special Reliability and Maintainability Data Studies. Reliability and maintainability data studies were carried out on the brine/hydrocarbon heat exchangers and condensers and the principal pumps and valves. The materials and environmental specifications presented in the FPS equipment specifications were taken into account. For example, the 29-4C brine/hydrocarbon heat exchanger and condenser tube material increases the projected reliability over stainless steel, carbon steel, or copper-nickel tubes. Limited utility company experience on heat exchangers with this tube material in brackish and salt water service was reviewed as well as laboratory test data. Results were compared with experience on carbon steel tubes in other geothermal plants and test installations. The purpose of these studies was to validate the equipment specifications with respect to achieving the plant and system availability targets. Results of these studies are published in References 13 through 15.
- Task F - Review Definitive Facility Layouts. The layout was reviewed from a maintainability point of view to determine the impact on the availability model.
- Task G - Review Definitive System Descriptions. The definitive design system descriptions were reviewed to provide the details of plant design and function. The availability model was updated to reflect changes.
- Task H - Review/Revise Final Facility Layouts. The final layout drawings of the physical scale model were reviewed. The layout was found to be compatible with the availability model. Findings are published in Reference 16.
- Task I - Review Final/Revised System Descriptions. The availability model was updated. This task was conducted in parallel with Task K.
- Task J - Equipment Specification Supplements. Availability data request supplements were prepared for the equipment on the preliminary ACIL. Reliability and maintainability specifications were prepared for the turbine-generator.
- Task K - Finalize Overall Plant Availability. The final equivalent availability model, presented in this report, is the principal output of this task. The final plant and system assessments have been compared with the availability targets and the final ACIL has been prepared.
- Task L - Review of Operations and Maintenance Procedures. This task will be accomplished in Phase 2.
- Task M - Development of an Availability Data Collection System. This task will be accomplished in Phase 2.
- Task N - Administrative and Computer Costs. Used for accounting purposes only.

- Task 0 - Instrumentation and Control Configurations Analysis. Typical configurations of digital and analog designs offered by the principal vendors were analyzed and recommendations made relative to optimum configurations. Redundancy criteria were provided. The procurement specification was reviewed and comments prepared. The results of the study are published in Reference 17.

4. DESCRIPTION OF ANALYTICAL METHODS AND ASSUMPTIONS

4.1 BRIEF SYSTEM DESCRIPTIONS

4.1.1 BRINE HEAT EXCHANGE AND RETURN SYSTEM

Brine from the brine supplier will be manifolded at the inlet and outlet of the brine/hydrocarbon heat exchangers to provide for two parallel strings of four units in series. The heat exchanger configuration as shown in Figure 1 allows for isolation of each of the two strings.

Cooled brine will be piped to the inlet manifold of the four brine return pumps. Each pump is capable of handling 25% of the brine flow. The appropriate valving is provided to allow isolation of any single pump.

Bypass piping around the heat exchangers and the pumps will be used during startup and shutdown operations.

4.1.2 HYDROCARBON SYSTEM

The hydrocarbon system, also shown in Figure 1, contains the isobutane/isopentane working fluid. The hydrocarbon is heated by brine in the brine/hydrocarbon heat exchangers. The high pressure vapor is routed via a liquid knockout drum to the turbine. Turbine control and stop valves are provided. In addition, a bypass valve is to be used during startup and shutdown to bypass the working fluid directly to the condensers. The expanded hydrocarbon vapor is condensed in two hydrocarbon condensers, which are cooled with recirculating cooling water. The condensed hydrocarbon is pumped to the suction of the four hydrocarbon booster pumps using vertical hydrocarbon condensate pumps for each of the two condensers. The condensate pumps are rated at 25% of full load flow so that two are required for the normal flow from each of the two condensers, while the four condensate booster pumps are each capable of 25% full flow. Each condensate pump and each condensate booster pump will be manifolded and appropriately valved to permit isolation of individual pumps.

Minimum flow bypasses are provided for each booster pump. Hydrocarbon is then routed back to the brine/hydrocarbon heat exchangers or through two filter coalescers. The filtered hydrocarbon is then sent back to the system through the loop seals or to the storage tank in the hydrocarbon unloading and recovery system. Makeup is provided by a transfer pump in the unloading and recovery system which pumps hydrocarbon from the storage tank to the condenser reservoirs.

4.1.3 HYDROCARBON RELIEF AND FLARE SYSTEM

The flare system is designed for maximum discharge of hydrocarbon such as would occur during a full power turbine trip. Otherwise, only small amounts of hydrocarbon would be flared during purging and recharging

FIGURE 1. BRINE AND HYDROCARBON SYSTEMS SIMPLIFIED P&ID

operations. Relief valves will discharge into relief headers which are routed via a knockout drum to the flare stack. The knockout drum has drain pumps to prevent liquid carryover to the stack.

The flare stack will be equipped with a flare tip and pilot ignition system. A water seal will prevent air from entering the flare header. An inert gas purge will be introduced between the water seal and the fluidic or molecular seal which is located just below the flare tip.

The flare tip will be elevated to prevent endangering personnel or equipment by thermal radiation.

4.1.4 HYDROCARBON UNLOADING AND RECOVERY SYSTEM

Two 100% capacity hydrocarbon transfer pumps (Figure 2) are provided to pump liquid from delivery truck to either storage tank or from the isopentane tank to the isobutane tank.

Vapor and liquid hydrocarbon are recovered after plant shutdown when maintenance of major equipment is necessary. Four pumps are provided to recover liquid hydrocarbon. Vapor is depressurized to a compressor suction drum. A reciprocating compressor and service water cooled condenser are provided to compress, condense, and return the recovered hydrocarbon to the storage tank.

The storage tank is equipped with a circulation pump and service water cooled heat exchanger to cool the stored hydrocarbon. A transfer pump is used to provide makeup hydrocarbon to the hydrocarbon system from the storage tank.

Nitrogen gas from the inert gas system is used to purge the equipment for which access is required. Purge gas is routed to the flare stack (see Section 4.1.3) until hydrocarbon concentration decreases sufficiently. Evacuation is performed with a vacuum pump before the equipment is opened to the atmosphere for personnel access.

4.1.5 COOLING WATER SYSTEM

The majority of the cooling water system (Figure 3) capacity is required for cooling the hydrocarbon condensers (see Section 4.1.2). Cooling water is also used for the service water system (see Section 4.1.6). Water heated in the condensers is routed to the cooling tower which consists of 10 functionally separate cells. Water falling through the cooling tower is cooled by evaporation with air flow enhanced by axial fans (one per cell). The cooled water is collected in a pond where chemical treatment takes place. Chemical treatment includes sulfuric acid, solids dispersants, corrosion inhibitors, and chlorine. Makeup water from the water treatment and distribution system is added to the canal in an area which has a high degree of mixing. Total dissolved solids concentration is controlled by continuous blowdown extracted from the cooling tower headers. Cooling water from the pond flows through

FIGURE 2. SIMPLIFIED P&ID OF HYDROCARBON UNLOADING AND RECOVERY SYSTEM

FIGURE 3. COOLING WATER SYSTEM SIMPLIFIED P&ID

debris screens to a pump pit. Two vertical 50% capacity cooling water pumps take suction from the pump pit and supply cooling water to the hydrocarbon condensers.

4.1.6 SERVICE WATER SYSTEM

The service water system (Figure 4) is a closed loop system to plant equipment with substantial cooling loads, such as the hydrocarbon recovery condenser, hydrocarbon cooler, oil coolers, compressor coolers, and diesel generators jacket cooler.

Service water storage is provided by a tank with a closely monitored water level. Two 100% capacity service water pumps supply cooling water to the loads mentioned above. Each pump can be isolated for maintenance and is equipped with a minimum flow bypass control valve.

The heated water flows through two 100% capacity service water coolers and back to the storage tank. Water to make up for system losses is supplied by the water treatment and distribution system and is added downstream of the cooler.

Two vertical 100% capacity pumps draw water from the cooling water pond (see Section 4.1.5) and pump it through the service water cooler to the cooling tower header. Each of the service water cooler pumps can be isolated for maintenance.

4.1.7 INERT GAS SYSTEM

The nitrogen storage tank (Figure 5) is a cryogenic container used for bulk liquid nitrogen storage. Liquid nitrogen is transported to the plant by truck and is transferred to the storage tank.

To prevent a vacuum within the storage volume as liquid nitrogen is withdrawn, a pressure building coil (heating coil) is provided in a pipe loop to vaporize some liquid nitrogen and increase tank pressure. A relief valve is provided in the event of tank overpressure as a backup to the overpressure control valve.

The line to the flare stack for continuous purge is from the pressure building coil pipe loop.

Liquid nitrogen supplied to the nitrogen vaporizers (E-15A and E-15B) is vaporized by forced draft heat exchange with ambient air. The vaporization load is divided equally between the two vaporizers. Fan start is dependent on manual operation. A relief valve is provided upstream of the control valves at the discharge of each vaporizer.

Two electrical nitrogen vaporizers (E-26A and E-26B) are also provided in parallel with the previous vaporizers (E-25A and E-25B). Electrical heater coils vaporize the nitrogen. One will normally operate while the other is a spare.

FIGURE 4. SERVICE WATER SYSTEM SIMPLIFIED P&ID

FIGURE 5. INERT GAS SYSTEM SIMPLIFIED P&ID

Each set of vaporizers has its own temperature control valve and pressure control valve which will close upon low temperature and pressure conditions.

The inert gas system vacuum pump is used to evacuate the hydrocarbon equipment after nitrogen purging. The discharge is sent to the flare header.

4.1.8 ELECTRICAL SUBSTATION AND DISTRIBUTION

The electrical distribution single line diagram is shown in Figure 6. The electrical power distribution system consists of a double-ended substation and all the transformers, buses, and breakers necessary to supply power to the plant. The double-ended substation connects to the Imperial Irrigation District (IID) network through the Calxico line and Valley line. The substation voltage is stepped down from 34.5 kV to 13.8 kV by the main transformer. The main transformer connects to the plant main distribution bus on which the generator and auxiliary transformer are connected. The auxiliary transformer steps down the voltage from 13.8 kV to 4.16 kV and supplies power to two 350 MVA switchgear buses which service the brine return pumps, hydrocarbon condensate pumps, hydrocarbon booster pumps, and cooling water pumps. Both of the 350 MVA switchgear buses supply power to the double-ended plant switchgear buses through two 4.16 kV/480V transformers. The plant switchgear buses supply power to the plant service air compressors, service water circulation pumps, hydrocarbon unloading and recovery pumps, and two plant motor control center buses each.

Both of the 350 MVA buses supply power to two double-ended cooling tower switchgear buses through four 4.16 kV/480V transformers. The cooling tower switchgear buses supply power to the cooling tower fans, makeup water pumps, service water cooler pumps, fire water pump, and two cooling tower motor control buses.

4.1.9 PLANT AND INSTRUMENT AIR SYSTEM

Two 100% capacity single-stage reciprocating air compressors are provided to supply instrument air to plant loads (see Figure 7). Air is drawn through screened, elevated intake stacks through the compressor stage. The air then flows through an aftercooler. The aftercooler transfers heat to the service water system (see Section 4.1.6). Water traps catch condensed water collected downstream of the aftercooler.

A common air receiver provides storage capacity for the instrument air from both trains. A backup instrument air source is available from the plant air compressor, which is a two-stage compressor with an intercooler and aftercooler also cooled by service water.

A crosstie is provided downstream of the plant air receiver to a point upstream of the instrument air prefilters. The crosstie central valve has isolation valves and a manual bypass.

BUS LOAD LIST

SWG-02

BRINE RETURN PUMP MOTOR P-11AM
BRINE RETURN PUMP MOTOR P-11CM
MAIN COOLING WATER PUMP MOTOR P-16AM
H/C BOOSTER PUMP MOTOR P-13A-M
H/C BOOSTER PUMP MOTOR P-13B-M
H/C CONDENSATE PUMP MOTOR P-12AM
H/C CONDENSATE PUMP MOTOR P-12BM

SWG-03

BRINE RETURN PUMP MOTOR P-11BM
BRINE RETURN PUMP MOTOR P-11DM
MAIN COOLING WATER PUMP MOTOR P-16BM
H/C BOOSTER PUMP MOTOR P-13CM
H/C BOOSTER PUMP MOTOR P-13DM
H/C CONDENSATE PUMP MOTOR P-12CM
H/C CONDENSATE PUMP MOTOR P-12DM
FIRE PUMP MOTOR P-21M

SWG-04

EMERGENCY DIESEL MCC-05

SWG-07

PLANT SERVICE AIR COMPRESSOR MOTOR C-04M
H/C UNLOADING AND RECOVERY COMPRESSOR
MOTOR C-01M

SWG-05

COOLING TOWER FAN MOTOR FA-01M
COOLING TOWER FAN MOTOR FA-02M
COOLING TOWER FAN MOTOR FA-03M
COOLING TOWER FAN MOTOR FA-04M
COOLING TOWER FAN MOTOR FA-05M
SERVICE WATER COOLER PUMP MOTOR P-17AM
SERVICE WATER CIRCULATION PUMP MOTOR
P-18AM
MAKE UP WATER PUMP MOTOR P-25CM

SWG-06

COOLING TOWER FAN MOTOR FA-06M
COOLING TOWER FAN MOTOR FA-07M
COOLING TOWER FAN MOTOR FA-08M
COOLING TOWER FAN MOTOR FA-09M
COOLING TOWER FAN MOTOR FA-10M
SERVICE WATER COOLER PUMP MOTOR P-17BM
SERVICE WATER CIRCULATION PUMP MOTOR
P-18BM
MAKE UP WATER PUMP MOTOR P-25AM
MAKE UP WATER PUMP MOTOR P-25BM

FIGURE 6. ELECTRICAL DISTRIBUTION AND SUBSTATION SINGLE LINE DIAGRAM

FIGURE 7. PLANT AND INSTRUMENT AIR SYSTEM SIMPLIFIED P&ID

Redundant instrument air prefilters are located upstream of redundant pairs of air dryers. Redundant instrument air afterfilters are located downstream of the dryers. The clean, dry air then enters the instrument air distribution system.

4.2 ANALYTICAL METHODS

4.2.1 SYSTEM MODELS

The systems analyses employed the use of four analytical models to quantify system availability/reliability. The four model types used are the GO methodology, availability block diagram, event trees, and fault trees. Event tree models were used in alternate configuration cost-benefit studies on the heat exchangers (Reference 6) and the condensers (Reference 7), and fault tree models were used in the unit substation alternate configurations analyses (Reference 8).

The system availability assessments, based on the "approved for design" P&IDs, were conducted utilizing the GO methodology and the availability block diagram modeling technique.

Availability/reliability block diagrams serve a number of purposes:

- Illustrate those equipment/component operations necessary for system success.
- Establish a system model for quantitative availability analyses.
- Enhance availability related communication.
- Show single failure points.

A block diagram of a set of components is frequently used to depict their functional arrangement and to aid in achieving their operational goal. Items arranged in series illustrate that all the items are necessary for system success. Items arranged in parallel illustrate that there are alternate paths to success. Unlike diagrams for physical processes, component arrangement in reliability/availability block diagrams may or may not correspond to their actual physical interconnections. In the availability engineering sense, block diagrams depict the interrelationships between system elements and show requirements for successful system operation.

GO methodology is a success oriented modeling technique similar to the availability method. Components or component failure/success modes are represented by symbols combined in the logical configuration of the system required for operation. There are 17 operators available for logical representation, a significant increase over block diagram operators.

A GO model consists primarily of the GO operators. The GO operators are represented by circles and are put together in logical and/or functional relationships which generally represent the physical equipment of the real system. A supertype is a subsystem of GO operators used more than

once in the model and is combined into a block for ease of modeling. The operator types are explained in the following illustration.

Type Number - The specific type of operator used from the following table.

Kind Number - The number that represents the component the operator is modeling.

Note: AND/OR gates do not have kind numbers.

<u>Type</u>	<u>Function</u>
1	Two-State Component - Good State/Fail State
2	"OR" Gate
3	Three State Component - Good State/Fail State/Fail State
10	"AND" Gate
11	M out of N Gate
13	AND/OR Combination Gate

Diagrams representing the Heber plant systems are presented in Figures 8 through 15. The following list shows which modeling technique was used for the final assessment of each system.

<u>Figure</u>	<u>System</u>	<u>Method</u>
1	Brine Heat Exchanger and Return	GO
1	Hydrocarbon	GO
2	Hydrocarbon Unloading and Recovery	GO
3	Cooling Water	GO
4	Service Water	GO
5	Inert Gas	Block Diagram
6	Electrical Distribution	GO
7	Plant and Instrument Air	Block Diagram

FIGURE 8. BRINE SYSTEM GO MODEL

FIGURE 9. HYDROCARBON SYSTEM GO MODEL

The diagram illustrates a water distribution network. It begins with a source labeled 'S-1' (a triangle) connected to a horizontal line of components: 1-2 CV, 1-3 TNK, 1-4 GV, 1-4 GV, 1-4 GV, 1-5 COMP, 1-6 COND, 1-7 PRV, 1-4 GV, 1-4 GV, 1-4 GV, 1-8 GV, 1-7 PRV, 1-9 COND, 1-11 AGV, 1-4 GV, and 1-2 CV. This line connects to a junction labeled '10'. From this junction, the system branches into several paths:

- Top Branch:** Junction '10' connects to 1-4 GV, then 1-2 CV, which leads to another junction '10'. This junction connects to 1-4 GV and 1-4 GV, which then leads to a final junction '10'.
- Middle Branch:** Junction '10' connects to a horizontal line of components: 1-7 PRV, 1-8 GV, 1-4 GV, 1-12 PMP, 1-2 CV, 1-4 GV, 1-7 PRV, 1-11 AGV, 1-7 PRV, 1-8 GV, 1-8 GV, 1-8 GV, and 1-13 GV.
- Bottom Branch:** Junction '10' connects to a horizontal line of components: 1-7 PRV, 1-13 GV, 1-13 GV, 1-13 GV, 1-8 GV, and 1-8 GV. This line connects to a junction labeled '10', which then connects to 1-8 GV. This junction further branches into two parallel paths, each containing 1-4 GV, 1-12 PMP, 1-2 CV, and 1-16 GV, which then connect to a junction labeled '2'. From junction '2', the paths continue through 1-16 GV, 1-7 PRV, and 1-4 GV to a final junction '10'.
- Left Branch:** Junction '10' connects to a horizontal line of components: 1-15 TNK, 1-11 AGV, and 1-7 PRV.
- Bottom Branch:** Junction '10' connects to a horizontal line of components: 1-4 GV, 1-11 AGV, 1-4 GV, 1-8 COND, 1-4 GV, 1-4 GV, 1-12 PMP, 1-2 CV, 1-4 GV, 1-11 AGV, 1-4 GV, and 1-4 GV.

The final junction '10' on the right connects to a horizontal line of components: 1-17 TNK, 1-4 GV, 1-4 GV, 1-8 GV, 1-12 PMP, 1-2 CV, 1-4 GV, and 1-11 AGV.

LEGEND

- AGV - AUTOMATIC GATE VALVE
- COND - CONDENSER
- COMP - COMPRESSOR
- CV - CHECK VALVE
- GV - GATE VALVE
- PMP - PUMP
- PRV - PRESSURE RELIEF VALVE
- TNK - TANK

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GO MODEL FOR COOLING WATER LOOP

GO MODEL FOR SERVICE WATER LOOP

FIGURE 12. SERVICE WATER SYSTEM GO MODEL.

FIGURE 13. ELECTRICAL DISTRIBUTION SYSTEM GO MODEL

FIGURE 14. PLANT AND INSTRUMENT AIR SYSTEM BLOCK DIAGRAM

FIGURE 15. CONTINUATION OF PLANT AND INSTRUMENT AIR SYSTEM BLOCK DIAGRAM

4.2.2 PLANT MODEL

Based on the results of subsystem availability assessments and failure mode, effects, and criticality analyses, 29 subsystem failure configurations were defined. These failure configurations for the base case are presented in Table 4 with the estimated power plant output expressed as a percentage of the nominal output of 45 MWe net. For each failure configuration, the subsystem failure rate

$$\lambda = \left(\frac{1}{\text{MTBF}} \right)$$

and the subsystem repair rate

$$\mu = \left(\frac{1}{\text{MTTR}} \right)$$

values were computed based on the referenced PLG reports. These failure configurations by themselves and in selected combinations (up to a maximum of two failure configurations) were translated into 91 plant states. These states are shown in Table 5 with the estimated power plant output for each state.

The equivalent availability (or average productivity) is the product of three matrices as shown below:

$$\text{Equivalent Availability} = [S][T][P]$$

where [S] is a row matrix, the elements of which are the probability of being in each of the states. [T] is the transition matrix, the elements of which represent the probability of moving from one state to another or remaining in the same state. The transition probabilities are functions of the failure rate

$$\lambda = \left(\frac{1}{\text{MTBF}} \right)$$

and the repair rate

$$\mu = \left(\frac{1}{\text{MTTR}} \right)$$

for the failure configurations associated with the states involved in the transition. [P] is the productivity matrix, a column vector, the elements of which are the plant output expressed as a decimal fraction of rated output.

The transition matrix is presented in abbreviated form in Table 6.

The equivalent availability was evaluated using the PLG computer code MATRIX. The initial condition for the [S] matrix was set as a 1.0 probability for state 1 (the nonfailed state) and a zero for the other states.

TABLE 4. SYSTEM FAILURE CONFIGURATIONS

System Configurations	Capacity (percent)	System/ Subsystem Failure Rate λ	System/ Subsystem Repair Rate μ
1. No Failures in All Subsystems	100	--	--
2. Generator	0	3.41-5	5.00-3
3. Turbine	0	1.89-4	4.55-3
4. Brine/Hydrocarbon Heat Exchanger	50	3.17-4	1.82-2
5. Brine/Hydrocarbon Heat Exchanger	0	2.51-8	3.27-3
6. Condenser	0	6.60-5	9.09-3
7. Condenser	0	1.09-9	8.33-4
8. Balance of Brine System	75	9.36-4	2.42-2
9. Balance of Brine System	50	4.41-5	2.29-2
10. Balance of Brine System	0	2.69-6	1.87-2
11. Balance of Hydrocarbon System	75	6.51-4	2.53-2
12. Balance of Hydrocarbon System	50	3.49-4	3.21-2
13. Balance of Hydrocarbon System	0	1.87-4	2.98-2
14. Cooling Water System	50	1.74-4	4.69-2
15. Cooling Water System	0	1.11-4	6.13-2
16. Service Water System	0	1.19-7	5.81-3
17. Plant and Instrument Air System	0	1.75-6	6.50-2
18. Hydrocarbon Transfer and Recovery	0	3.04-4	3.24-2
19. Electrical System	50	2.19-5	9.24-3
20. Electrical System	0	3.56-5	1.15-2

NOTE: Exponential notation is indicated in abbreviated form;
i.e., 3.41-5 = 3.41×10^{-5} .

TABLE 4 (continued)

System Configurations	Capacity (percent)	System/ Subsystem Failure Rate λ	System/ Subsystem Repair Rate μ
21. Instrumentation and Control	0	1.25-4	1.25-1
22. Waste Treatment System	0	1.00-6	1.25-1
23. Flare System	0	1.00-6	1.25-1
24. Hot Brine Well Pumps and Piping	94	1.19-3	2.08-2
25. Hot Brine Well Pumps and Piping	88	1.75-4	2.08-2
26. Hot Brine Well Pumps and Piping	0	3.13-5	2.08-2
27. Brine Injection Wells	88	3.5-4	2.08-2
28. Brine Injection Wells	75	1.88-5	2.08-2
29. Brine Injection Wells	0	3.13-5	2.08-2

NOTE: Exponential notation is indicated in abbreviated form;
i.e., 1.25-4 = 1.25×10^{-4} .

TABLE 5. PLANT STATES

Plant State \ Failure Configuration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Capacity (percent)
1	X																							X						100
2																														94
3																														88
4																														88
5																														88
6																														88
7																														75
8								X																						75
9																														75
10								X																						75
11								X																						75
12								X																						75
13								X																						75
14								X																						75
15								X																						75
16								X																						75
17																														75
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24																														75
25																														75
26																														75
27																														75
28																														75
29																														75
30																														75

TABLE 5 (continued)

Plant State \ Failure Configurations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Capacity (percent)
31				X															X											50
32						X			X																					50
33						X						X																		50
34						X								X																50
35						X													X											50
36									X			X																		50
37									X					X																50
38									X										X											50
39									X			X		X																50
40												X							X											50
41												X		X					X											50
42				X				X											X											50
43						X		X																						50
44								X				X																		50
45								X						X																50
46								X											X											50
47				X							X																			50
48						X					X																			50
49									X		X																			50
50											X			X																50
51											X								X											50
52				X							X																			50
53						X																					X	X		50
54									X																		X	X		50
55												X															X	X		50
56														X													X	X		50
57				X						X									X									X		50
58						X																			X					50
59																									X					50
60						X			X																X					50

TABLE 5 (continued)

Plant State \ Failure Configurations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Capacity (percent)
61												X		X										X						50
62																								X						50
63														X					X					X						50
64				X																				X						50
65						X													X						X					50
66									X																X					50
67										X				X											X					50
68												X		X											X					50
69																			X						X					50
70				X																							X			50
71						X																				X	X			50
72									X																	X	X			50
73												X														X	X			50
74														X												X	X			50
75																			X							X	X			50
76		X																									X			0
77			X																											0
78					X																									0
79							X																							0
80										X																				0
81													X																	0
82															X															0
83																X														0
84																	X													0
85																		X												0
86																				X										0
87																					X									0
88																						X								0
89																							X							0
90																										X				0
91																												X		0

TABLE 6. ABBREVIATED TRANSITION MATRIX

Column Rows	1	2	3	4	5	6	7	8	9 . . .	91
1	①	λ_{24}	λ_{25}	λ_{27}			λ_8	λ_{11}	λ_{28}	
2	μ_{24}	②			λ_{27}					
3	μ_{25}		③			λ_{27}				
4	μ_{27}			④	λ_{24}	λ_{25}				
5	μ_{24} μ_{27}	μ_{27}		μ_{24}	⑤					
6	μ_{25} μ_{27}		μ_{27}	μ_{25}		⑥				
7	μ_8						⑦			
8	μ_9							⑧		
9	μ_{28}								⑨	
.										
.										
.										
91										⑨①

NOTE: ① - Diagonal elements are 1- Σ all entries in that row.

After each iteration, the equivalent availability is computed and the updated [S] matrix is determined. The [S] values are the eigenvalues of the problem and the matrix product, [S][P], for the steady state represents the eigenvector. The steady state equivalent availability by state is presented in Section 5.2.

4.2.3 SPARE PARTS REQUIREMENTS FOR AVAILABILITY CRITICAL ITEMS

The parts associated with each of the equipment items on the ACIL were derived partially from vendor drawings and documents for the turbine and generator. However, vendor drawings on the turbine casing and blading design are not yet available. Estimates of the number of parts on the turbine and generator were made based on outline sketches. For some of the other ACIL items, the equipment specification prepared by Fluor Power Services-provided sketches and spare parts recommendations were used. Proposal documentation on successful bidders was also used to define the parts. The ACIL parts list should be considered preliminary at this stage of the project.

The appropriate method for determining the spare parts level should consider the cost of maintaining the inventory as well as the unavailability cost, given that a part is not available when needed. This is a probabilistic calculation which includes the probability of running out, given the spare parts inventory policy, and the probability distribution of reorder time. At the present time, the probability distribution of reorder time cannot be formulated from existing vendor information.

The standard approach of computing the spare parts level required to ensure a specified confidence level of not running out over a specified calendar period (without replenishing) was utilized. The Poisson discrete probability distribution was used to estimate the likelihood of failures. The constant failure rate

$$\lambda = \frac{1}{MTBF}$$

(where MTBF = mean time between failures) was used to compute the mean number of failures over a specified calendar period. The equation used was to compute the probability of n or less failures

$$P(n) = \sum_{0}^n \frac{(T/MTBF)^n}{n!} e^{-T/MTBF}$$

Thus, for a stocking level of n, a confidence limit equal to P(n) was computed. Figure 16 presents a graphical representation which was utilized. This figure is based on a 95% confidence level. A calendar time period (without replenishing) was picked as 12 months. The correction for unavailability due to forced outages would be approximately 12 months x 0.9 availability = 10.8 months. The 12-month line was used in the calculations since the difference in interpolation in the figure is not significant and availability values greater than 0.9 may occur.

The results of the analysis are presented in Section 5.4.

4.3 RELIABILITY AND MAINTAINABILITY DATA

The initial development of the reliability and maintainability data base reported in the Availability Data Book Conceptual Design Phase in Reference 1 was based on data from the PLG data base for equipment in similar environments and data from Fluor Corporation on equipment in a hydrocarbon environment. The latter data come from gas pipeline experience. The effect of the brine environment on brine system component reliability was estimated.

The data base was updated during the definitive design period and is presented in the PLG report on the initial definitive design system availability assessments (Reference 2) and a revision to the availability data book (Reference 3). Concurrently, special reliability and maintainability data studies were undertaken for major components for the specific environment and the materials indicated in the equipment specifications developed by FPS. These studies were carried out for the principal pumps (Reference 11), the brine/hydrocarbon heat exchangers and hydrocarbon condensers (Reference 12), and the principal valves (Reference 13). For example, data on heat exchangers in salt and brackish water environments were reviewed and used to establish the brine/hydrocarbon heat exchanger failure rate. The results of these studies were used to modify the data base. The data base used for this final assessment is shown in Table 7.

FIGURE 16. SPARE PARTS QUANTITIES AT 95% CONFIDENCE LEVEL

TABLE 7. RELIABILITY AND MAINTAINABILITY DATA

Equipment Description	λ (hours ⁻¹)	MTBF (hours)	MTTR (hours)
<u>Brine System</u>			
Manual Valve			
Failure to Operate	5.3-7	1.89+6	32.3
Leakage/Rupture	1.6-5	6.25+4	32.3
Automatic Valve			
Failure to Operate	2.7-6	3.70+5	32.3
Leakage/Rupture	2.7-5	3.70+4	32.3
Check Valve			
Failure to Operate	8.0-5	1.25+4	32.2
Leakage/Rupture	1.6-5	6.25+4	32.3
Heat Exchanger	3.96-5	2.53+4	85
Brine Return Pump	1.35-4	7.40+3	56
<u>Hydrocarbon Systems</u>			
Manual Valve (Vapor)			
Failure to Operate	1.0-6	1.0+6	32.3
Leakage/Rupture	1.0-5	1.0+5	32.3
Manual Valve (Liquid)			
Failure to Operate	5.3-7	1.89+6	32.3
Leakage/Rupture	1.6-5	6.25+4	32.3
Automatic Valve (Vapor)			
Failure to Operate	2.7-6	3.70+5	32.3
Leakage/Rupture	2.7-5	3.70+4	32.3
Automatic Valve (Liquid)			
Failure to Operate	2.7-6	3.70+5	32.3
Leakage/Rupture	4.0-5	2.5+4	32.3
Check Valve (Liquid)			
Failure to Operate	2.7-6	3.70+5	32.3
Leakage/Rupture	1.6-5	6.25+4	32.3
Pressure Relief Valve (Vapor)			
Failure to Operate	1.7-5	5.88+4	32.3
Leakage/Rupture	1.6-6	6.25+5	32.3

NOTE: Exponential notation is indicated in abbreviated form;
 i.e., 5.3-7 = 5.3×10^{-7} . Notation 1.89+6 = 1.89×10^6 .

TABLE 7 (continued)

Equipment Description	λ (hours ⁻¹)	MTBF (hours)	MTTR (hours)
<u>Hydrocarbon Systems</u> (continued)			
Pressure Relief Valve (Liquid)			
Failure to Operate	1.86-5	5.38+4	32.3
Leakage/Rupture	1.86-5	5.38+4	32.3
Condensate Pump	3.0-5	3.33+4	56
Booster Pump	3.0-5	3.33+4	56
Condenser	3.3-5	3.03+4	110
Tank	1.0-8	1.0+8	25
Compressor	4.0-5	2.5+4	24
Transfer Pump	3.0-5	3.33+4	12.8
Tank Cooling Pump	3.0-5	3.33+4	12.8
Recovery Pump	3.0-5	3.33+4	12.8
<u>Cooling Water and Service Water Systems</u>			
Manual Valve			
Failure to Operate	5.3-7	1.89+6	32.3
Leakage/Rupture	1.33-6	7.52+5	32.3
Automatic Valve			
Failure to Operate	2.7-6	3.70+5	32.3
Leakage/Rupture	2.7-6	3.70+5	32.3
Check Valve			
Failure to Operate	2.7-6	3.70+5	32.3
Leakage/Rupture	1.33-6	7.52+5	32.3
Pressure Relief Valve			
Failure to Operate	1.86-5	5.38+4	32.3
Leakage/Rupture	1.86-5	5.38+4	32.3
Tank	1.0-7	1.0+7	40

NOTE: Exponential notation is indicated in abbreviated form;
i.e., 1.86-5 = 1.86×10^{-5} . Notation 5.38+4 = 5.38×10^4 .

TABLE 7 (continued)

Equipment Description	λ (hours ⁻¹)	MTBF (hours)	MTTR (hours)
<u>Cooling Water and Service Water Systems (continued)</u>			
Service Water Coolers	3.3-5	3.03+4	71
Service Water Pumps	2.7-5	3.70+4	12.8
Pond	1.0-8	1.0+8	100
Screen, Sluice Gate	1.0-5	1.0+5	15
Cooling Water Pumps	2.7-5	3.70+4	56
<u>Electrical System</u>			
Circuit Breaker (Air)			
Fail to Open	4.10-7	2.44+6	62
Fail Open	4.10-7	2.44+6	62
Circuit Breaker (Oil)			
Fail to Open	7.25-6	1.38+5	15
Fail Open	7.25-6	1.38+5	15
High Voltage Line			
Fail Open	6.13-7	1.63+6	27
Switch			
Fail to Open	1.41-7	7.09+6	15
Fail Open	1.41-7	7.09+6	15
Transformer	2.31-6	4.33+5	453
Bus	3.60-7	2.78+6	5
<u>Control Air System</u>			
Compressor	2.0-5	5.0+4	48
Air Filter	2.0-5	5.0+4	4
Check Valve	5.0-7	2.0+6	12
Pressure Control Valve	3.0-5	3.33+4	24
Manual Valve	1.0-6	1.0+6	12

NOTE: Exponential notation is indicated in abbreviated form; i.e.,
3.3-5 = 3.3×10^{-5} . Notation 3.03+4 = 3.03×10^4 .

TABLE 7 (continued)

Equipment Description	λ (hours ⁻¹)	MTBF (hours)	MTTR (hours)
<u>Control Air System</u> (continued)			
Air Receiver	5.0-7	2.0+6	24
Air Dryer	1.0-5	1.0+5	24
Air Refrigerant System	9.35-5	1.07+4	24
Level Control Valve	2.0-5	5.0+4	24
Air Screen	5.0-7	2.0+6	12

NOTE: Exponential notation is indicated in abbreviated form;
i.e., 5.0-7 = 5.0×10^{-7} . Notation 2.0+6 = 2.0×10^6 .

5. RESULTS

5.1 SYSTEM RESULTS

The system equivalent unavailability results based on the "approved for design" issue of the P&IDs are presented in Table 8. The target value is also shown for comparison. All systems met their target values with the exception of the hydrocarbon system, the hydrocarbon unloading recovery system, and the cooling water system. The last system is only slightly below the target (0.996 versus 0.998 target). The system equivalent unavailability expressed in annual forced outages (hours per year) is also shown in Table 8. The principal forced outage contributors of each system are also shown. These contributors were used to update the availability critical items list which is presented in Table 2.

5.2 PLANT RESULTS

The plant model yielded a plant equivalent availability of 0.9033 which is equivalent to 35.3 per year of forced and deferred corrective maintenance outages, including 30 outage days per year for planned maintenance. The equivalent assessed availability is 0.8211, equivalent to 65.3 days per year of outages.

The steady state equivalent availability by plant state is presented in Table 9.

The higher assessed equivalent availability relative to the target may be attributed to the fact that the targets are conservative. Although redundant condensate pumps, condensate booster pumps, and brine return pumps were eliminated in the "approved for design" drawings, the increase in equivalent unavailability was more than compensated by a reduction in the number of hydrocarbon valves which are directly connected to the hydrocarbon system. The effect of the external leakage failure mode for these valves is shutdown of the plant. The assessed equivalent availability of the turbine-generator based on historical data of similar machines was found to be higher than the target value which was conservative and was based on large steam turbine-generators.

5.3 RECOMMENDATIONS LIST

The recommendations list presented in Table 3 contains a running list of PLG recommendations that were developed as the design progressed. It has been augmented to include recommendations pertinent to the "approved for design" drawings.

5.4 SPARE PARTS QUANTITIES FOR ACIL EQUIPMENT

The results are shown in Table 10. The PLG recommendations are shown for each part with a few exceptions where information is insufficient to determine the number of parts in the equipment. Recommendations for spare parts quantities provided by the manufacturers and/or FPS are shown if they were available from documentation. When vendor drawings are

TABLE 8. SYSTEM EQUIVALENT UNAVAILABILITIES

System	Contributors	Equivalent Failure Rate	MTTR	Target Equivalent Unavailability	Assessed Equivalent Unavailability	Assessed Outages (hours per year)
1. Hydrocarbon System	Condensers	6.60-5	110		7.24-3	64
	Pumps	6.00-5	56		3.39-3	29
	Valves	4.64-4	31.9		2.55-2	130
System Total		5.57-4	39.1	1.5-2	2.55-2	223
2. Brine System	Heat Exchangers	1.58-4	55.6		8.80-3	77
	Pumps	1.35-4	54		7.51-3	64
	Valves	1.24-4	31.4		3.90-3	34
System Total		4.17-4	47.2	2.4-2	1.97-2	175
3. Hydrocarbon Unloading and Recovery System	Vapor Recovery	1.04-5	33.2		3.45-4	3
	Liquid Recovery	1.18-5	29.1		3.43-4	3
	Transfer to Condensers	9.75-5	26.5		2.58-3	22
	Isopentane Transfer	4.52-6	29.6		1.34-4	1
	Storage Cooling	1.80-4	33.3		6.00-3	53
System Total		3.04-4	30.9	3.0-3	9.40-3	82
4. Cooling Water System	Pumps	2.70-5	56		1.50-3	13
System Total		1.98-4	18.5	2.0-3	3.66-3	32
5. Electrical System	Transformers	4.62-6	453		2.10-3	18.4
System Total		2.88-5	95	5.0-3	2.73-3	23.9
6. Instrumentation and Control		1.25-4	8	1.0-3	1.00-3	9
7. Service Water System		1.19-7	172	5.0-3	2.04-5	.2
8. Plant and Instrument Air		1.75-6	15.4	5.0-3	2.69-5	.2

NOTE: Exponential notation is indicated in abbreviated form; i.e., 6.60-5 = 6.60×10^{-5} .

TABLE 9. EIGENVECTOR VALUES

Rank	Plant State	System	Capacity	Description	Equivalent Unavailability	Hours Per Year
1	77	3	0	Turbine	3.28-2	287
2	85	18	0	Hydrocarbon Unloading and Recovery	7.42-3	64.3
3	7	8	75	Brine	7.33-3	63.6
4	21	4	50	Heat Exchanger	6.47-3	56.1
5	76	2	0	Generator	5.39-3	46.7
6	22	6	90	Condenser	5.23-3	45.3
7	81	13	0	Hydrocarbon System	4.96-3	43.4
8	8	11	75	Hydrocarbon System	4.87-3	42.7
9	24	12	50	Hydrocarbon System	4.15-3	36.4
10	2	24	94	Hot Brine Well Pumps	2.59-3	22.5
11	86	20	0	Electrical	2.45-3	21.2
12	4	27	88	Cold Brine Injection Well Pumps	1.51-3	13.1
13	82	15	0	Cooling Water	1.43-3	12.4
14	25	14	50	Cooling Water	1.43-3	12.4
15	90	26	0	Hot Brine Well Pumps and Piping	1.19-3	10.3
16	91	29	0	Cold Brine Injection Wells and Piping	1.19-3	10.3
17	26	19	50	Electrical	8.53-4	7.4
18	87	21	0	Instrumentation and Control	7.90-4	6.8
19	3	25	88	Hot Brine Well Pumps	7.52-4	6.5
20	23	9	50	Brine System	7.19-4	6.2
Balance of Contributors					3.70-3	32.4
Total					9.67-2	847
Availability = .9033						
Unavailability = .0967 847 hours per year						

NOTE: Exponential notation is indicated in abbreviated form; i.e., 3.28-2 = 3.28×10^{-2} .

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TABLE 10. SPARE PARTS ANALYSIS OF CRITICAL ITEMS FOR HEBER GEOTHERMAL PLANT

Sheet 1 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer (Elliott)	
Hydrocarbon Turbine	1	A		350	1	5,300	5,300				-	
Journal Bearing (Inlet End)	1	A	Journal Bearing Assembly			68,000	68,000	0.4	1	No Specific Recommendations in Fluor Specifications	1	
Journal Bearing (Discharge End)	1	A	Journal Bearing Assembly			68,000	68,000	0.4	1		1	
Thrust Bearing Assembly (Active Side)	1	A	Thrust Bearing Assembly			68,000	68,000	0.4	1		1	
Thrust Bearing Assembly (Inactive Side)	1	A	Thrust Bearing Assembly			68,000	68,000	0.4	1		1	
Rotor Labyrinths	2†	CΔ	Labyrinth Assembly			600,000	300,000	0.12	0		1 Set	
Wind Back Seals	2†	A	Wind Back Seals			600,000	300,000	0.12	0		1 Set	
<u>Seal Assembly</u>												
Carbon Rings	2	A	Carbon Rings			50,000	25,000	0.9	1		2	
Stationary Sleeves	2	A	Stationary Sleeves			100,000	50,000	0.7	1		2	
Rotating Rings	2	A	Rotating Rings			50,000	25,000	1.4	2		2	
Sleeve Seals (Outboard)	2	A	Sleeve Seals			50,000	25,000	1.4	2		2	

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = shutdown decision is a function of leakage severity.

TABLE 10 (continued)

Sheet 2 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer (Elliott)	
Hydrocarbon Turbine (continued)												
Contact Seal Springs	2 Setst	A	Contact Seal Springs			20,000	10,000	2	2 Sets	No Specific Recommendations in Fluor Specifications	2 Sets	
Shutdown Pins	2 Setst	A	Shutdown Pins			20,000	10,000	2	2 Sets		2 Sets	
Nylon Inserts	2 Setst	A	Nylon Inserts			20,000	10,000	2	2 Sets		2 Sets	
Rotor	1†					400,000	400,000	0.13	0			
Rotating Blades	~ 300†					600,000	2,000	8.0	3 Per Stage			
Stationary Blades	~ 300†					600,000	2,000	8.0	3 Per Stage			

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = shutdown decision is a function of leakage severity.

TABLE 10 (continued)

Sheet 3 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Hydrocarbon Valves				126	2	2,000						
30" E/H Butterfly Valves (Turbine Inlet)	4	CA	Turbine Inlet Butterfly Valves			34,000	8,500	2.3	3	No Specific Recommendations in Fluor Specifications	Vendor Data Not Yet Available	Failure to Open Excessive External Leakage
12" E/H Butterfly Valves (Turbine Inlet)	1	CA	Turbine Inlet Butterfly Valves			34,000	34,000	0.79	1			Failure to Open Excessive External Leakage
6" x 8" Pressure Relief Valve (Turbine Exhaust to Condensers)	2	CA	Turbine Exhaust Pressure Relief Valve			54,000	27,000	0.87	1			Failure to Open Excessive External Leakage
30" Manual Butterfly Valves (4 for Condensate Pump Inlet and 2 for Heat Exchanger Outlet)	6	CA	Condensate Pump and Heat Exchanger Butterfly Valves			61,000	10,200	2	2			Failure to Open Excessive External Leakage
18" Check Valve (4 for Condensate Pump Outlet and 4 for Booster Pump Outlet)	8	CA	Condensate Pump and Booster Pump Check Valves			54,000	6,750	2.8	3			Failure to Open Excessive External Leakage
18" Manual Butterfly Valve (4 for Booster Pump Inlet and 4 for Booster Pump Outlet)	8	CA	Booster Pump Butterfly Valves			61,000	7,629	2.9	3			Failure to Open Excessive External Leakage

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = shutdown decision is a function of leakage severity. Failure of the valve to open will cause shutdown.

TABLE 10 (continued)

Sheet 4 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Hydrocarbon Valves (continued)												
3/4" x 1" Pressure Safety Valve (Booster Pump Outlet Header)	1	CA	Booster Pump Header Pressure Safety Valve			54,000	54,000	0.6	1	No Specific Recommendations in Fluor Specifications	Vendor Data Not Yet Available	Excessive External Leakage
24" Manual Butterfly Valve (Heat Exchanger Inlet)	2	CA	Heat Exchanger Inlet Butterfly Valve			61,000	30,500	0.8	1			Failure to Open Excessive External Leakage
24" Air-Operated Butterfly Valve (Heat Exchanger Inlet)	2	CA	Heat Exchanger Inlet Butterfly Valve			24,000	12,000	1.8	2			Failure to Open Excessive External Leakage
3" x 4" Pressure Safety Valve (Heat Exchanger Inlet)	2	CA	Heat Exchanger Inlet Pressure Safety Valve			54,000	27,000	0.87	1			Excessive External Leakage
30" Air-Operated Butterfly Valve (Heat Exchanger Outlet)	2	CA	Hydrocarbon Flow System			34,000	17,000	1.3	1			Failure to Open Excessive External Leakage
10" Manual Gate Valve (Booster Pump Outlet)	4	CA	Hydrocarbon Flow System			63,000	15,800	1.4	1			Failure to Open Excessive External Leakage
2" Manual Gate Valve (Heat Exchanger Outlet)	4	CA	Hydrocarbon Flow System			63,000	15,800	1.4	1			Failure to Open Excessive External Leakage

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = shutdown decision is a function of leakage severity. Failure of the valve to open will cause shutdown.

TABLE 10 (continued)

Sheet 5 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Brine/Hydrocarbon Heat Exchanger	8			77	3	25,000						
Gaskets	8 Sets	CΔ	Gaskets			Replace On Disassembly			8 Sets	8 Sets		
Tubes	24,000	CΔ	Tubes			520,000	21.6	-	310 (=1.3%)	1%		
Nuts and Bolts	†	CΔ	Nuts and Bolts			-	-	-	-	10% Per Exgr.		
Plugs	†	CΔ				ΔΔ	-	-	620	-		
											Vendor Data Not Yet Available	

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

- Δ = shutdown decision is a function of leakage severity.

- ΔΔ = assume each tube replaced is plugged before replacement. Therefore, the number of plugs equals twice the number of spare tubes.

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

TABLE 10 (continued)

Sheet 6 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Brine Return Pumps Heat Exchanger	4			66	4	7,400						
Thrust Bearing (Kingsbury Type)	4†	CA	Thrust Bearing Assembly			68,000	17,000	1.3	1			
Radial Bearing (Split Sleeve Type)	4 Each End†	CA	Radial Bearing			68,000	17,000	1.3	1 Per Each End			
Pump Seals	8†	CA	Pump Seals			50,000	6,250	3	3			
Rotor	4†	CA	Rotor			400,000	100,000	0.35	1			
Impeller	4†	CA	Impeller			200,000	50,000	0.58	1			
Gaskets	4 Set†	CA	Gaskets			Replace On Disassembly		-	4 Sets			
Wearing Rings	8†	CA	Wearing Rings			80,000	10,000	2	2			
Shaft Sleeves	8†	CA	Shaft Sleeves			100,000	12,500	1.7	2			
Lube Oil Filter Cartridge	4†	CA	Lube Oil Filter Cartridge			ΔΔ	ΔΔ	-	.8			
Coupling	4†	CA	Coupling			200,000	50,000	0.58	1			
Motor	4†	CA	Pump Motor Assembly			70,000	17,500	1.3	1			
Throat Bearings	4 Each End†	CA	Throat Bearings			68,000	17,000	1.3	2 Per Each End			

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

** When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = taking one pump out of service will result in a plant capacity reduction of 25%.

- ΔΔ = function of contamination of hydrocarbon system. Assumed two spare cartridges per filter.

TABLE 10 (continued)

Sheet 7 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer (Electric Machinery)	
Hydrogen Cooled Generator	1			60	1	30,000						
<u>Stator Assembly</u>												
Top Half Stator Coil	†	A	Top Half Stator Coil			-	-	-	-			
Bottom Half Stator Coil	†	A	Bottom Half Stator Coil			-	-	-	-			
Winding Material	†	A	Winding			-	-	-	-			
Main Lead Bushing	1†	A	Main Lead Bushing			68,000	68,000	0.4	1			
<u>Gas Supply System</u>												
Gaskets	†	CA	Gaskets			Replace On Disassembly		-	1 Set			
<u>Gland Seal and Bearing Assembly</u>												
Bearing	1†	A	Bearing			68,000	68,000	0.4	1			
Seal Strip Segment	1 Set†	A	Seal Strip Segment			68,000	68,000	0.4	1 Set			
Lock Strip Segment	1 Set†	A	Lock Strip Segment			68,000	68,000	0.4	1 Set			
Gland Seal Ring (EE)	1 Set†	A	Gland Seal Ring (EE)			50,000	50,000	0.5	1 Set			
Gland Seal Ring (TE)	1 Set†	A	Gland Seal Ring (TE)			50,000	50,000	0.5	1 Set			

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = shutdown decision is a function of leakage severity.

TABLE 10 (continued)

Sheet 8 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer (Electric Machinery)	
<u>Gland Seal and Bearing Assembly (continued)</u>												
Gaskets	1 Set†	A	Gaskets			Replace On Disassembly		-	1 Set	No Specific Recommendations in Fluor Specifications	Vendor Data Not Yet Available	
Insulating Washers	1 Set†	A	Insulating Washers			Replace On Disassembly		-	1 Set			
Insulating Tubes	†	B	Insulating Tubes			-	-	-	2 Sets			
Glass Window	†	C	Glass Window			-	-	-	2			
<u>Gas Cooler Assembly</u>												
Gasket and Material	†	C	Gaskets	-		Replace On Disassembly		-	1 Set			
<u>Seal Oil Supply Assembly</u>												
Pump Seals	2 Setst	CA	Pump Seals			50,000	25,000	0.9	1 Set			
Pump Bearings	1 Set† Each End	CA	Pump Bearings			68,000	68,000	0.8 Each End	2 Sets			
Oil Filter Cartridge	†	CA	Oil Filter Cartridge			ΔΔ	ΔΔ	-	2			
Gaskets	†	CA	Gaskets			Replace On Disassembly		-	1 Set			
<u>DC Brushless Exciter</u>												
Resistor	†	A	Resistor			-	-	-	-			

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = usually, there is a standby seal pump available which can be aligned to the system. Thus, it will not be necessary to shut down the system.

- ΔΔ = function of contamination.

TABLE 10 (continued)

Sheet 9 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer (Electric Machinery)	
<u>DC Brushless Exciter (continued)</u>												
Conventional Diode	†	A	Conventional Diode			-	-	-	-	No Specific Recommendations in Fluor Specifications	Vendor Data Not Yet Available	
Fuse	†	A	Fuse			-	-	-	-			
Bearing	1†	A	Exciter Bearing			68,000	68,000	0.4	1			
Seal Strip Segment	1 Set†	B	Seal Strip Segment			68,000	68,000	0.4	1 Set			
Lock Strip Segment	1 Set†	B	Lock Strip Segment			68,000	68,000	0.4	1 Set			
Stator Field Coil	†	A	Stator Field Coil			-	-	-	-			
Seal Gasket	1 Set†	B	Seal Gasket			Replace On Disassembly		-	1 Set			
Seal Cover Gasket	1 Set†	B	Seal Cover Gasket			Replace On Disassembly		-	1 Set			
<u>Miscellaneous Gaskets</u>												
Gaskets	†	B	Gaskets			Replace On Disassembly		-	1 Set			
Cement	†	B	-			-	-	-	-			
Toluol	†	B	-			-	-	-	-			

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

TABLE 10 (continued)

Sheet 10 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer (Electric Machinery)	
<u>Type M Resistor</u>												
Resistor Unit	†	A	Resistor Unit			-	-	-	-			
Miscellaneous Bearings	1 Set†	A	Miscellaneous Bearings			68,000	68,000	0.4	1 Set	No Specific Recommendations in Fluor Specifications		
Diodes/Fuses	†	A	Diodes/Fuses			-	-	-	-		1 Set	
Hydrogen Seals	1 Set†	A	Hydrogen Seals			50,000	50,000	0.6	1 Set		1 Set	
Oil Seals	1 Set†	A	Oil Seals			50,000	50,000	0.6	1 Set		1 Set	
Voltage Regulator	1†	A	Voltage Regulator			-	-	-	-		1	
Flexible Coupling	1	A	Coupling			200,000	200,000	0.2	0		-	Manufactured by Bendix

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

TABLE 10 (continued)

Sheet 11 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Hydrocarbon Condenser	2			32	7	30,000						
Gaskets	2 Sets†	CA	Gaskets			Replace On Disassembly		-	2 sets	2 sets		
Tubes	32,120	CA	Tubes			520,000	16.2	400	400 1.2%	1%		
Nuts & Bolts	†	CA	Nuts and Bolts			-	-	-	-	10%		
Tube Plugs	†	-	Tube Plugs			ΔΔ	-	-	800	250		
Tube Expanders	†	-	Tube Expanders			-	-	-	-	1 Set Per Condenser		
Rollers	†	-	Rollers			-	-	-	-	1 Set Per Condenser		

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = taking one condenser out of service will result in a 50% reduction in plant capacity. Taking both condensers out of service will cause plant shutdown.

- ΔΔ = assume each tube replaced is plugged before replacement. Therefore, the number of plugs equals twice the number of spare tubes.

TABLE 10 (continued)

Sheet 12 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Brine System Valves				24	8							
30" Manual Butterfly Valve (1 for Heat Exchanger Inlet and 1 for Brine Return to Wells)	3	CA	Heat Exchanger Inlet/Brine Return Butterfly Valves			62,500	20,833	1.0	1	No Specific Recommendations in Fluor Specifications	Vendor Data Not Yet Available	Failure to Open Excessive External Leakage
24" Manual Butterfly Valve (4 for Heat Exchanger Trains and 3 for Pump Inlet Header)	7	CA	Heat Exchanger Train Inlet/ Pump Inlet Header Butterfly Valves			62,500	8,930	2.1	2			Failure to Open Excessive External Leakage
24" Air-Operated Butterfly Valve (2 for Heat Exchanger Train Inlet and 2 for Outlet, 1 for Bypass)	5	CA	Heat Exchanger Train Inlet and Outlet Butterfly Valves			37,000	7,400	2.6	3			Failure to Open Excessive External Leakage
3" Manual Gate Valve (Heat Exchanger Train Outlet)	3	CA	Heat Exchanger Train Outlet Butterfly Valves			62,500	20,833	1.1	1			Failure to Open Excessive External Leakage

LEGEND: *Impact of failure

- A = causes shutdown.
- B = no effect.

- C = other (as explained).

- Δ = shutdown decision is a function of leakage severity. Failure of the valve to open will cause shutdown.

- † = Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

TABLE 10 (continued)

Sheet 13 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Floor	Manufacturer	
Brine System Valves (continued)												
18" Manual Butterfly Valve (Pump Inlet)	8	CA	Pump Inlet Butterfly Valve			62,500	7,812	2.5	3	No Specific Recommendations in Floor Specifications	Vendor Data Not Yet Available	Failure to Open Excessive External Leakage
18" Check Valve (Pump Outlet)	4	CA	Pump Outlet Check Valve			12,500	3,125	5.0	5			Excessive External Leakage
12" Manual Gate Valve (Bypass Piping)	5	CA	Warmup Circulation Piping			62,500	12,500	1.8	2			Failure to Open Excessive External Leakage
12" Air-Operated Gate Valve (Bypass Piping)	2	B	Pump Outlet (P-11B, P-11C)			37,000	18,500	1.3	1			Failure to Open Excessive External Leakage
12" Check Valve (Bypass Piping)	2	B	Warmup Recirculation			12,500	6,250	3.0	3			Failure to Open Excessive External Leakage

LEGEND: *Impact of failure
 - A = causes shutdown.
 - B = no effect.
 - C = other (as explained).

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- A = shutdown decision is a function of leakage severity. Failure of the valve to open will cause shutdown.

- † = Not shown on available vendor drawings.

TABLE 10 (continued)

Sheet 14 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Hydrocarbon Condensate Pumps	4			15	10	34,000						
Throat Bearings	4 Each End†	CA	Throat Bearings			68,000	17,000	1.3	1 Per Each End			
Tandem Mechanical Seals	8†	CA	Mechanical Seals			50,000	6,250	3	3			
Impeller Wear Rings	8†	CA	Wear Rings			80,000	10,000	2	2			
Stainless Steel Shaft Sleeves	8†	CA	Shaft Sleeves			100,000	12,500	1.7	2			
Thrust Bearing	4†	CA	Thrust Bearing Assembly			68,000	17,000	1.3	1			
Radial Bushings/Bearings	4 Each End†	CA	Radial Bearings			68,000	17,000	1.3	1 Per Each End			
Gaskets	4 Setst	CA	Gaskets			Replace On Disassembly		-	4 Sets			
Rotor	4†	CA	Rotor			400,000	100,000	0.35	1			
Impeller	4†	CA	Impeller			200,000	50,000	0.58	1			
Lube Oil Filter Cartridge	4†	CA	Lube Oil Filter Cartridge			ΔΔ	ΔΔ	-	8			
Coupling	4†	CA	Coupling			200,000	50,000	0.58	1			
Motor	4†	CA	Motor Assembly			70,000	17,500	1.3	1			

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

- Δ = taking one pump out of service will result in a 25% reduction in plant capacity.

- ΔΔ = function of contamination of hydrocarbon system. Assumed 2 spare cartridges per filter.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

TABLE 10 (continued)

Sheet 15 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Hydrocarbon Booster Pumps	4			15	11	34,000						
Wear Rings	8†	CA	Wear Rings			80,000	10,000	2	2	No Specific Recommendations in Fluor Specifications	Vendor Data Not Yet Available	
Throat Bushings	4 Each End†	CA	Throat Bushings			68,000	17,000	1.3	1 Per Each End			
Tandem Mechanical Seals	8†	CA	Mechanical Seals			50,000	6,250	3	3			
Thrust Bearing (Kingsbury Type)	4†	CA	Bearing Assembly			68,000	17,000	1.3	1			
Coupling	4†	CA	Coupling			200,000	50,000	0.58	1			
Shaft Sleeves	8†	CA	Shaft Sleeves			100,000	12,500	1.7	2			
Gaskets	4 Setst	CA	Gaskets			Replace On Disassembly		-	4 Sets			
Rotor	4†	CA	Pump Assembly			400,000	100,000	0.35	1			
Impeller	4†	CA	Pump Assembly			200,000	50,000	0.58	1			
Lube Oil Filter Cartridge	4†	CA	Lube Oil System			ΔΔ	ΔΔ	-	8			
Motor	4†	CA	Pump-Motor Assembly			70,000	17,500	1.3	1			

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = taking one pump out of service will result in a 25% reduction in plant capacity.

- ΔΔ = function of contamination of hydrocarbon system. Assumed 2 spare cartridges per filter.

TABLE 10 (continued)

Sheet 16 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Main Cooling Water Pumps	2			13	12	37,000						
Shaft Seals	4†	CA	Shaft Seals			50,000	12,500	1.7	2	No Specific Recommendations in Fluor Specifications	Vendor Data Not Yet Available	
Coupling	2†	CA	Coupling			200,000	100,000	1	1			
Thrust Bearings (Kingsbury Type)	2†	CA	Thrust Bearing Assembly			68,000	34,000	1	1			
Shaft Sleeves	4†	CA	Shaft Sleeves			100,000	25,000	0.9	1			
Sleeve Bearings	2 for Each End	CA	Sleeve Bearings			68,000	34,000	1	1			
Wear Rings	4†	CA	Wear Rings			80,000	20,000	1	1			
Gaskets	2 Sets†	CA	Gaskets			Replace On Disassembly		-	2 Sets			
Rotor	2†	CA	Rotor			400,000	200,000	0.2	0			
Impeller	2†	CA	Impeller			200,000	100,000	1	1			
Lube Oil Filter Cartridge	2†	CA	Lube Oil Filter Cartridge			AA	AA	-	4			
Motor	2†	CA	Motor Assembly			70,000	35,000	1	1			

LEGEND: *Impact of failure
 - A = causes shutdown.
 - B = no effect.
 - C = other (as explained).

- Δ = taking the pump out of service will result in a 50% reduction in plant capacity.
 - ΔΔ = function of water contamination. Assumed 2 spare cartridges per filter.

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

TABLE 10 (continued)

Sheet 17 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Hydrocarbon Recovery System Compressor				8	13	25,000						
Thrust Bearing	1†	B	Thrust Bearing Assembly			68,000	68,000	0.4	1	No Specific Recommendations in Fluor Specifications	Vendor Data Not Yet Available	
Sleeve Bearings	1 Per Each End†	B	Sleeve Bearings			68,000	34,000	0.7	1			
Lube Oil Filter Cartridge	1†	B	Lube Oil Filter Cartridge			Δ	Δ	-	2			
Seals	2†	B	Mechanical Seals			50,000	25,000	0.9	1			
Wear Rings	2†	B	Wear Rings			80,000	40,000	0.7	1			
Gaskets	1 Set†	B	Gaskets			Replace On Disassembly		-	2 Sets			
Air Filter	1†	B	Air Filter			Δ	Δ	-	2			
Coupling	1†	B	Coupling			200,000	200,000	0.2	0			
Motor	1†	B	Motor			70,000	70,000	0.4	1			
Shaft Sleeves	2†	B	Shaft Sleeves			100,000	50,000	0.7	1			

LEGEND: *Impact of failure

- A = causes shutdown.

- B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = depends upon contamination. Assumed 2 spare cartridges per filter.

TABLE 10 (continued)

Sheet 18 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Hydrocarbon Liquid Recovery Pumps	4			3	14	33,000						
Thrust Bearing	4†	CA	Thrust Bearing Assembly			68,000	17,000	1.3	1	No Specific Recommendations in Fluor Specifications	Vendor Data Not Yet Available	
Sleeve Bearings	4 Each End†	CA	Sleeve Bearings			68,000	17,000	1.3	1 Per Each End			
Pump Seals	8†	CA	Pump Seals			50,000	6,250	3	3			
Rotor	4†	CA	Rotor			400,000	100,000	0.39	1			
Impeller	4†	CA	Impeller			200,000	50,000	0.58	1			
Gaskets	4 Setst	CA	Gaskets			Replace On Disassembly		-	4 sets			
Wearing Rings	8†	CA	Wear Rings			80,000	10,000	2	2			
Shaft Sleeves	8†	CA	Shaft Sleeves			100,000	12,500	1.7	2			
Lube Oil Filter Cartridge	4†	CA	Lube Oil Filter Cartridge			AA	AA	-	8			
Coupling	4†	CA	Coupling			200,000	50,000	0.58	1			
Motor	4†	CA	Motor Assembly			70,000	17,500	1.3	1			

LEGEND: *Impact of failure

- A = causes shutdown.
- B = no effect.
- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = taking one pump out of service will result in a 25% reduction in plant capacity.
- ΔΔ = function of contamination of hydrocarbon system. Assumed 2 spare cartridges per filter.

TABLE 10 (continued)

Sheet 19 of 19

Equipment/Component	Required Number N	Impact of Failure of Component on System Operation*	Line Replaceable Unit (LRU)**	Outage in Hours Per Year	Availability Critical Items List Number (ACIL Number)	Mean Time Between Failures (MTBF) in Hours	MTBF N	Predicted Number of Spares for One Calendar Year (Figure 16)	Recommended Number of Spare Parts			Remarks
									PLG	Fluor	Manufacturer	
Hydrocarbon Transfer Pump	1			3	15	33,000						
Thrust Bearing	1†	CA	Thrust Bearing Assembly			68,000	68,000	0.4	1			
Sleeve Bearings	1 Per Each End†	CA	Sleeve Bearings			68,000	68,000	0.4	1 per each end			
Pump Seals	2†	CA	Pump Seals			50,000	25,000	0.92	1			
Rotor	1†	CA	Rotor			400,000	400,000	0.13	0			
Impeller	1†	CA	Impeller			200,000	200,000	0.2	0			
Gaskets	1 Set†	CA	Gaskets			Replace On Disassembly			-	1 set		
Wearing Rings	2†	CA	Wearing Rings			80,000	40,000	0.7	1			
Shaft Sleeves	2†	CA	Shaft Sleeves			100,000	50,000	0.7	1			
Lube Oil Filter Cartridge	1†	CA	Lube Oil Filter Cartridge			ΔΔ	ΔΔ	-	2			
Coupling	1†	CA	Coupling			200,000	200,000	0.2	0			
Pump Motor	1†	CA	Motor Assembly			70,000	70,000	0.4	1			

LEGEND: *Impact of failure
 - A = causes shutdown.
 - B = no effect.

- C = other (as explained).

†Not shown on available vendor drawings.

**When vendor drawings are available, the LRU will be redefined as subassembly items, if appropriate.

- Δ = depends upon the leakage of hydrocarbon in various equipment of the plant and how long the system can do without replenishing the hydrocarbon.

- ΔΔ = function of contamination of hydrocarbon. Assumed 2 spare cartridges per filter.

available for all equipment/components on the ACIL, the line replaceable unit (LRU) will be redefined as subassemblies of the equipment/component if appropriate. For example, typical valves' LRUs are seat rings, packing ring, stem, motorized operator, etc.

There is close agreement on most of the spare parts quantities identified by PLG and Elliott for the turbine. There is close agreement on the generator for common parts identified by PLG and the Electric Machinery Company for the generator/exciter. For the hydrocarbon condenser, there is close agreement between the PLG and FPS recommendations on spare tubes. For most of the balance of ACIL equipment, no FPS or manufacturer spare parts quantities are currently available.

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