Annex L

Reliability Survey of 600 to 1800 kW Diesel and Gas-Turbine Generating Units

By
Clayton A. Smith, Michael D. Donovan, and Michael J. Bartos

Conference Record of the IEEE Industrial and Commercial Power Systems Technical Conference
Chicago, Illinois
May 8–11, 1989

IEEE Transactions on Industry Applications
July/August 1990, pp. 741–755

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CLAYTON A. SMITH, MICHAEL D. DONOVAN, ASSOCIATE MEMBER, IEEE, AND MICHAEL J. BARTOS

Abstract—In 1988 the U.S. Army Engineering and Housing Support Center (EHSC) sponsored a study of the reliability, availability, and maintainability (RAM) characteristics of diesel and gas-turbine power systems producing less than 2 MW. The study, conducted by ARINC Research Corporation, included collection and examination of source data for power systems at commercial and military facilities operating in continuous or standby service. A data base of system, subsystem, and component RAM data was established. These data will be useful in the design of primary and standby power systems for military or commercial facilities.

Introduction

THE U.S. Army Engineering and Housing Support Center (EHSC) sponsored a study [7] of the reliability, availability, and maintainability (RAM) characteristics of small diesel and gas-turbine power systems. The study, conducted by ARINC Research, produced a data base of system, subsystem, and component RAM data for industrial and military power systems in both continuous and standby service. An updated RAM data base was needed to support the analysis of power systems at command, control, communications, and intelligence (C^3I) installations worldwide. EHSC wanted higher confidence in the validity of the power-system reliability data used to analyze C^3I system reliability. Currently available RAM data were outdated and were not tailored to EHSC's specific requirements. Further, these data did not permit identifying component failure rates in alternative prime-mover designs.

The primary objective was to obtain data reflecting the reliability improvements resulting from advances in power-plant (prime-mover) technology since completion of the last comprehensive RAM study more than 15 years earlier. An additional objective was to provide data on the major components that failed in each system, together with data on the reliability of the prime mover. The information will be used in the evaluation of C^3I power-generation systems.

The prime movers of interest were diesel and gas-turbine generators ranging from 600 to 1800 kW. The diesel-generator configurations evaluated included both packaged systems and units with auxiliary support systems. Each of these types was categorized as standby and continuous duty. Because most gas-turbine systems in the size range of interest are configured as packaged units, the gas-turbine generators were categorized only by type of duty. Thus six categories were addressed:

- continuous-duty auxiliary diesels,
- standby auxiliary diesels,
- continuous-duty package diesels,
- standby package diesels,
- continuous-duty gas turbines,
- standby gas turbines.

Paper ICPSD 89-02, approved by the Power Systems Engineering Committee of the IEEE Industry Applications Society for presentation at the 1989 Industrial and Commercial Power Systems Annual Technical Conference, Detroit, MI, April 29-May 3. Manuscript released for publications January 9, 1990.

C. A. Smith and M. D. Donovan are with ARINC Research Corporation, 2551 Riva Road, Annapolis, MD 21401.

M. J. Bartos is with the U.S. Army Engineering and Housing Support Center, Fort Belvoir, VA 20060.

IEEE Log Number 9035434.

Methodology

The data collection comprised five tasks: 1) review existing data bases and reports, 2) identify data sources, 3) collect field data, 4) reduce data and prepare data base, and 5) calculate RAM statistics. These tasks are described in the following subsections.

Review Existing Data Bases and Reports

The results of previous and ongoing efforts in the collection of RAM data were reviewed to determine their applicability to the selected diesel and gas-turbine categories. Data bases such as the Government Industry Data Exchange Program (GIDEP) [1] and the Institute of Nuclear Power Operations (INPO) Nuclear Plant Reliability Data System (NPRDS) [5] were investigated, but they were found to contain minimal detail on power plants in the size ranges addressed by the study. Several manufacturers provided the results of studies on reliability, starting reliability, and unit availability conducted in preparation for customer presentations or proposals. The RAM measures from these studies were not included in the data base, because the objectivity and accuracy of the data could not be validated.

Identify Candidate Data Sources

Three methods were used to identify as candidate data sources the industrial and military facilities that operated diesel and gas-turbine power systems in the specified categories. Equipment manufacturers and distributors were asked to provide lists of customers having power systems that met the category definitions. U.S. military and Government agencies were similarly requested to provide names of equipment operators and sources of maintenance data. In addition, industrial directories were used to identify facilities representing typi-

USER SURVEY: DIESEL AND GAS-TURBINE GENERATORS

User/Company: __________
Address: __________
Contact: __________
Telephone: (__) __________
Date: __________
Application: __________
Staffing (No. of personnel and titles): __________

Items to Address:

How many units do you have on-site: __________
What are their ratings? __________
Are units standby or in continuous use? __________

	Yes	No
Is there a central data bank for maintenance information?	____	____
Do you collect maintenance data?	____	____
Do you collect operating data?	____	____
Do you record attempted and successful starts?	____	____
Do you keep logs for scheduled maintenance?	____	____
Do you have records of failure events?	____	____
Have there been at least five failures to the unit?	____	____
Do you track administrative and logistic time?	____	____
Can these data be sent to us for this effort?	____	____
Can ARINC Research obtain permission to review these records?	____	____
Is there a maintenance program in use?	____	____
If yes, is it the manufacturer's program?	____	____
Are spares kept on site?	____	____

Remarks: (Include brief history and line diagram of plant) User Code: __________

Fig. 1. User survey form.

cal power-system users, such as computer centers, small utility sites, and cogeneration plants. The candidate data sources identified through these surveys were listed in a project data base for sorting and screening during the data collection task.

Collect Data

Potential data sources were screened by means of a structured telephone survey technique, using the questions shown in Fig. 1, to identify candidate power plants for data collection. The objective of this screening was to determine the applicability, availability, and quality of operational, maintenance, and failure data. Plants were selected from a wide variety of applications (e.g., electric utilities, cogenerators, hospitals, airfields, military installations, and computer and communication facilities) to represent a range of variables such as manufacturer, plant usage, age, environment, and maintenance practices. Where possible, plants with at least ten years of operation and maintenance history were selected.

Selected power-plant operators with formal data collection systems were requested to mail facility descriptions and historical records of their operation and maintenance logs. Follow-up technical questions to clarify data interpretation were directed, via telephone conversations, to senior facility personnel.

The problem most frequently encountered in obtaining data from participating facilities was the level of effort required by the plant staff to assemble and reproduce the necessary records. To ensure the acquisition of representative data, site visits were made to facilities that could not respond to the mailing requests. Technical personnel experienced in plant operation and maintenance conducted these visits. In addition to records collection, visits typically included structured interviews with senior operations and maintenance personnel to obtain additional insights into failure events and maintenance tasks.

Twenty-two plants participated in the study, providing data on 71 power systems. The data represented 708 unit-years of operating experience, and all plants provided data for periods of 3 years or longer.

Develop Data Base

The source data on maintenance and failure events were arranged in a consistent record format for computer entry and validation. Data reduction was performed by examining events

TABLE I
RAM STATISTICS

RAM Measures	Formula Based on Period Hours	Formula Based on Operating Hours
Failure Rate (FR) (Failures per year)	$\frac{\text{No. of Failures}}{\text{Period Hours}} \times 8{,}760$	$\frac{\text{No. of Failures}}{\text{Operating Hours}} \times 8{,}760$
Mean Time Between Failures (MTBF) (Hours)	$\frac{\text{Period Hours}}{\text{No. of Failures}}$	$\frac{\text{Operating Hours}}{\text{No. of Failures}}$
Mean Time To Repair (MTTR) (Hours)	$\frac{\text{Total Repair Time}}{\text{No. of Failures}}$	$\frac{\text{Total Repair Hours}}{\text{No. of Failures}}$
Mean Time Between Planned Outages (MTBPO) (Hours)	$\frac{\text{Period Hours}}{\text{No. of Planned Outages}}$	$\frac{\text{Operating Hours}}{\text{No. of Planned Outages}}$
Mean Time To Maintain (MTTM) (Hours)	$\frac{\text{Planned Outage Hours}}{\text{No. of Planned Outages}}$	$\frac{\text{Planned Outage Hours}}{\text{No. of Planned Outages}}$
Mean Time Between Outages (MTBO) (Hours)	$\frac{\text{Period Hours}}{\text{No. of Outages}}$	$\frac{\text{Operating Hours}}{\text{No. of Outages}}$
Mean Downtime (MDT) (Hours)	$\frac{\text{Repair Hours + Planned Outage Hours}}{\text{No. of Outages}}$	$\frac{\text{Repair Hours + Planned Outage Hours}}{\text{No. of Outages}}$
Mean Time Between Corrective Maintenance (MTBCM) (Hours)	$\frac{\text{Period Hours}}{\text{No. of CMs}}$	$\frac{\text{Operating Hours}}{\text{No. of CMs}}$
Mean Time To Perform Corrective Maintenance (MTTCM) (Hours)	$\frac{\text{Corrective Maintenance Hours}}{\text{No. of CMs}}$	$\frac{\text{Corrective Maintenance Hours}}{\text{No. of CMs}}$
Availability, Operational (AO)	$\frac{\text{Period Hours} - \text{Repair Time} - \text{Planned Outage Hours}}{\text{Period Hours}}$	$\frac{\text{Operating Hours}}{\text{Operating Hours + Repair Hours + Planned Outage Hours}}$
Availability, Inherent (AI)	$\frac{\text{Period Hours} - \text{Repair Hours}}{\text{Period Hours}}$	$\frac{\text{Operating Hours}}{\text{Operating Hours + Repair Hours}}$
Reliability for 24 hours (R24)	$e^{-24/\text{MTBF}}$	$e^{-24/\text{MTBF}}$
Reliability for 720 hours (R720)	$e^{-720/\text{MTBF}}$	$e^{-720/\text{MTBF}}$

in the operating and maintenance records to identify the subsystem and component, the type of outage, the impact of the failure, and the action required to complete the maintenance. This information was coded according to the equipment, failure-impact, outage-type, and action codes listed in Appendix I.

Summary descriptions of each maintenance event were also prepared to provide insight into failure modes. Operating data for each unit—such as period hours, operating hours, starts, and start failures—were extracted from operating logs.

The event records produced by the data-reduction process were entered into a microcomputer data base. The data base architecture, developed with a commercially available data base management system, included features for automated checking for data-entry errors or inconsistencies. Following data entry, samples of records were randomly selected for validation against the raw data, ensuring consistency in application of the event coding scheme during data reduction.

Calculate RAM Statistics

The maintenance-event and operational data and the formulas shown in Table I were used to calculate RAM statistics for each of the six categories of power systems. The terms used in the formulas are defined in Table II.

RAM statistics were also calculated for subsystems and components in each category on the basis of both period hours and unit operating hours. Subsystem and component measures included failure rate (FR), mean time between failures (MTBF), mean time between corrective maintenance (MTBCM), mean time to perform corrective maintenance (MTTCM), and operational availability (AO).

The RAM statistics are intended for use by EHSC for a variety of analyses, evaluations, and planning studies for C^3I facility support systems. To meet the requirements of these applications, the RAM statistics were calculated using both period hours (i.e., calendar time) and operating hours.

RESULTS

The data base developed contains more than 6000 maintenance events, representing 708 unit-years and nearly one million operating hours. Data from units within each of the six categories were combined, because units within the same category are of similar technology and utilization. The unit-level RAM statistics for the six major categories from this data base are compiled in Tables III and IV. Data for subsystems and components within these categories are presented in Appendix II.

TABLE II
DEFINITIONS OF TERMS

Concurrent Maintenance Event (CC)	Maintenance action taken while unit is already in an outage
Corrective Maintenance Event (CM)	An event in which some equipment had to be repaired (outage-causing or not)
Corrective Maintenance Time	Time, in hours, required to complete a CM
Failure	An unexpected event that results in the interruption of electrical power at the generator output terminals
Forced-Outage Event (FO)	Failure
Noncurtailing Event (NC)	Maintenance action taken while the unit is available to produce power
Operating Hours	Number of hours the unit is producing power
Outage Event	Any interruption of electrical power at the generator output terminals
Period Hours (PH)	Number of calendar hours in a year (8,760)
Planned Outage Event (PO)	Outage taken for any scheduled reason (e.g., inspections, overhauls, cleaning)
Planned Outage Time	Time, in hours, taken to complete any planned outage event
Repair Time	Time, in hours, required to repair any failure
Unit-Years	Calendar hours in a year (8,760) multiplied by the number of units

TABLE III
COMPOSITE RAM STATISTICS BASED ON PERIOD HOURS

RAM Measures	Diesel Auxiliary		Diesel Package		Gas Turbine	
	Continuous	Standby	Continuous	Standby	Continuous	Standby
Number of Units	7	5	9	15	15	20
Period Hours	674,520	1,357,800	814,776	1,068,594	333,888	1,951,224
Number of Events	1,702	1,408	1,535	498	509	319
Unit Failures	302	198	408	118	174	70
Unit Outages (Planned and Forced)	1,311	615	959	365	385	278
Number of Corrective Maintenance Events	409	630	812	243	253	102
Failure Rate (Failures per Unit-Year)	3.9	1.2	4.3	0.9	4.5	0.3
MTBF (Hours)	2,233.5	6,857.4	1,997.0	9,055.8	1,918.8	27,874.6
MTTR (Hours)	2.9	2.8	6.4	3.9	7.2	111.6
MTBPO (Hours)	668.5	3,256.1	1,478.7	4,326.2	1,582.4	9,380.8
MTTM (Hours)	1.3	3.8	12.5	7.8	21.1	10.6
MTBO (Hours)	514.5	2,207.8	849.6	2,927.7	867.2	7,018.8
MDT (Hours)	1.7	3.5	9.9	6.5	14.8	36.1
MTBCM (Hours)	1,699.1	2,155.2	923.3	4,897.5	1,319.7	19,129.6
MTTCM (Hours)	2.8	2.9	4.3	2.9	5.7	77.4
AI	0.9986	0.9995	0.9967	0.9995	0.9962	0.9959
AO	0.9965	0.9984	0.9882	0.9977	0.9828	0.9948
R24	0.9893	0.9965	0.9880	0.9973	0.9875	0.9991
R720	0.7244	0.9003	0.6973	0.9235	0.6871	0.9745

Observations

The objective of the study was to compile a data base for use in the evaluation of power systems in C^3I facilities; thus no detailed analysis of the data was performed. However, some observations can be made from examination of the calculation results.

Table III indicates that, on the basis of period hours, units in the continuous-duty categories have similar failure rates. The period-based failure rates for the standby categories are much lower, because the low utilization of units in this category provides fewer opportunities for failures to occur.

The gas turbines exhibit the lowest failure rates of units in standby service. However, this is negated by long repair times. The raw data show that the large repair-time value is attributable to a relatively small number of long-duration events, including a main bearing failure (200 h), a reduction-gear failure (350 h), seven broker starter shafts (150 h each), and two events in which the turbine had to be sent back to the manufacturer (3000 h each). The starter-shaft problem was an initial design problem and has not occurred since the implementation of a design change to the part.

For the continuous-duty diesels with auxiliary systems, the failure rate based on operating hours, shown in Table IV, is significantly higher than that of the other categories in continuous service. This difference is attributable to the relatively low utilization of these diesels at the plants reporting in this category. These units were classified as continuous because they were scheduled for operation on a regular basis. However, most of them were operated in a cycling mode and operated only for several hours each day. The high failure rate results

TABLE IV
COMPOSITE RAM STATISTICS BASED ON OPERATING HOURS

RAM Measures	Diesel Auxiliary		Diesel Package		Gas Turbine	
	Continuous	Standby	Continuous	Standby	Continuous	Standby
Number of Units	7	5	9	15	15	20
Operating Hours	80.174	323.242	300.698	64.364	204.037	13.591
Number of Events	1.702	1.408	1.535	498	509	319
Unit Failures	302	198	408	118	174	70
Unit Outages (Planned and Forced)	1.311	615	959	365	385	278
Number of Corrective Maintenance Events	409	630	872	243	253	102
Failure Rate (Failures per Unit-Year)	32.9	5.3	11.8	16.0	7.4	45.1
MTBF (Hours)	264.4	1.632.5	737.0	545.4	1.172.6	194.1
MTTR (Hours)	2.9	2.8	6.4	3.9	7.2	111.6
MTBPO (Hours)	79.4	775.1	545.7	260.5	967.0	65.3
MTTM (Hours)	1.3	3.8	12.5	7.8	21.1	10.6
MTBO (Hours)	61.1	525.5	313.5	176.3	529.9	48.8
MDT (Hours)	1.7	3.5	9.9	6.5	14.8	36.1
MTBCM (Hours)	196.0	513.0	344.8	264.8	806.4	133.2
MTTCM (Hours)	2.8	2.9	4.3	2.9	5.7	77.4
AI	0.9889	N/A	0.9912	N/A	0.9938	N/A
AO	0.9713	N/A	0.9682	N/A	0.9720	N/A
R24	0.9132	0.9854	0.9680	0.9569	0.9797	0.8837
R720	0.0657	0.6434	0.3765	0.2671	0.5412	0.0245

from dividing the large number of failures induced in this type of operation by the relatively small number of operating hours.

Similarly, for the gas turbines in standby service, the high failure rate based on operating hours can be attributed to the relatively low utilization of these units. Most of the units in this category are used as emergency power supplies in computer or communications facilities. They are typically tested on a weekly or monthly basis and run for less than 1 h, with failures most likely to occur during the start sequence. On the basis of this limited operating time, the failure rate is high.

The subsystem and component data presented in Appendix II provide information on the causes of unit failures and unavailability. For example, problems with the standby gas turbines reside mostly in the starting system, particularly the battery. The fuel system, the generator, and the controls add to the overall failure rate. It is also of interest that much of the unavailability is due to inspection and cleaning actions, even though these actions do not contribute to the overall failure rate. For the continuous-duty auxiliary diesels, the failure rate is due largely to the engine itself, specifically the cylinder heads and the crankcase. Tracking these same components through all of the diesel categories shows them to have consistently the highest failure rate.

SUMMARY

Information collected through this study is useful in the design assessment of primary and standby power systems for military or commercial facilities. The unit-level RAM statistics for the six categories provide a baseline for comparison of RAM measures for a specific plant against a representative population similar in configuration and type of service. The subsystem and component data, in conjunction with appropriate modeling tools, provide a means for forecasting the availability performance of specific plant designs. Since the data base includes all component maintenance events rather than just outage failures, it provides information that will be useful in maintenance and logistic planning for power systems.

TABLE V
ACTION, FAILURE-IMPACT, AND OUTAGE-TYPE CODES

Action Codes		
CL	–	Cleaned
FL	–	Fixed Leak
IN	–	Inspection
MD	–	Modification
NA	–	No Action Taken
OV	–	Overhaul
PM	–	Preventive Maintenance
RA	–	Repaired
RC	–	Recalibrated
TS	–	Tested
Failure Impact		
0	–	No Failure
1	–	Failure Affected Only the Component
2	–	Failure Affected Component and Subsystem
3	–	Failure Affected Component, Subsystem, and Unit
Outage Type		
CC	–	Concurrent Maintenance
FO	–	Forced Outage
FS	–	Failure to Start
NC	–	Noncurtailing Maintenance
PO	–	Planned Outage

APPENDIX I

CODES

Failure-impact, outage-type, and the action codes are listed in Table V.

APPENDIX II

SUBSYSTEM AND COMPONENT DATA

Tables VI–XI reflect the RAM statistics based on equipment failure maintenance events for the units within the six categories. Components or subsystems that do not appear in a table did not experience any failure or maintenance events.

TABLE VI
SUBSYSTEM AND COMPONENT RAM MEASURES FOR CONTINUOUS-DUTY AUXILIARY DIESELS

Equipment	Period Hours					Operating Hours			
	Failures per Year	MTBF (Hours)	MTBCM (Hours)	MTTCM (Hours)	Operational Availability	Failures per Year	MTBF (Hours)	MTBCM (Hours)	MTTCM (Hours)
CONTROL & INSTRUMENTATION (DS–CTI)	0.08	112420.0	112420.0	1.7	1.0000	0.66	13362.3	13362.3	1.7
CIRCUIT BREAKERS (DS–CTI01)	0.05	168630.0	168630.0	1.5	1.0000	0.44	20043.5	20043.5	1.5
ELECTRICAL MODULE (DS–CTI02)	0.01	674520.0	674520.0	1.0	1.0000	0.11	80174.0	80174.0	1.0
SWITCHES (DS–CTI04)	0.01	674520.0	674520.0	3.0	1.0000	0.11	80174.0	80174.0	3.0
COOLING WATER SYSTEM (DS–CWT)	0.13	67452.0	44968.0	1.7	1.0000	1.09	8017.4	5344.9	1.7
COOLING WATER PUMP (DS–CWT02)	0.00	0.0	674520.0	0.5	1.0000	0.00	0.0	80174.0	0.5
ENGINE COOLING (DS–CWT03)	0.01	674520.0	674520.0	4.0	1.0000	0.11	80174.0	80174.0	4.0
THERMOSTAT (DS–CWT05)	0.00	0.0	674520.0	1.0	1.0000	0.00	0.0	80174.0	1.0
VALVES (DS–CWT07)	0.01	674520.0	337260.0	0.8	1.0000	0.11	80174.0	40087.0	0.8
WATER LINE (DS–CWT09)	0.06	134904.0	96360.0	0.9	1.0000	0.55	16034.8	11453.4	0.9
HEAT EXCHANGER (DS–CWT10)	0.03	337260.0	337260.0	5.0	1.0000	0.22	40087.0	40087.0	5.0
WATER HEADER (DS–CWT12)	0.01	674520.0	674520.0	2.0	1.0000	0.11	80174.0	80174.0	2.0
WATER MANIFOLD (DS–CWT13)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
DIESEL ENGINE (DS–ENG)	2.25	3899.0	3122.8	3.6	0.9984	18.90	463.4	371.2	3.6
BEARINGS (DS–ENG01)	0.08	112420.0	74946.7	2.9	0.9999	0.66	13362.3	8908.2	2.9
CYLINDER (DS–ENG02)	0.32	26980.8	20440.0	2.0	0.9999	2.73	3207.0	2429.5	2.0
CYLINDER HEADS (DS–ENG03)	0.99	8875.3	8225.9	4.0	0.9995	8.30	1054.9	977.7	4.0
DRIVE SHAFT (DS–ENG04)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
PISTONS (DS–ENG06)	0.26	33726.0	28105.0	4.7	0.9998	2.19	4008.7	3340.6	4.7
TURBO CHARGER (DS–ENG07)	0.01	674520.0	337260.0	4.0	1.0000	0.11	80174.0	40087.0	4.0
VALVES (DS–ENG08)	0.03	337260.0	224840.0	2.0	1.0000	0.22	40087.0	26724.7	2.0
RINGS (DS–ENG09)	0.31	28105.0	18230.3	3.5	0.9996	2.62	3340.6	2166.9	3.5
TIMING (DS–ENG10)	0.05	168630.0	134904.0	1.0	0.9998	0.44	20043.5	16034.8	1.0
INTAKE MANIFOLD (DS–ENG11)	0.08	112420.0	112420.0	3.2	1.0000	0.66	13362.3	13362.3	3.2
CRANKCASE (DS–ENG12)	0.01	674520.0	224840.0	15.0	0.9999	0.11	80174.0	26724.7	15.0
RODS (DS–ENG14)	0.01	674520.0	224840.0	3.7	1.0000	0.11	80174.0	26724.7	3.7
CAM (DS–ENG15)	0.08	112420.0	96360.0	2.0	0.9999	0.66	13362.3	11453.4	2.0
CHAIN DRIVE (DS–ENG17)	0.01	674520.0	337260.0	1.0	1.0000	0.11	80174.0	40087.0	1.0
TAPPET (DS–ENG18)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
EXHAUST SYSTEM (DS–EXH)	0.04	224840.0	96360.0	2.1	0.9997	0.33	26724.7	11453.4	2.1
EXHAUST SYSTEM (DS–EXH)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
EXPANSION JOINTS (DS–EXH03)	0.00	0.0	337260.0	4.0	1.0000	0.00	0.0	40087.0	4.0
PORTS (DS–EXH05)	0.01	674520.0	674520.0	0.5	0.9997	0.11	80174.0	80174.0	0.5
EXHAUST MANIFOLD (DS–EXH06)	0.03	337260.0	337260.0	0.5	1.0000	0.22	40087.0	40087.0	0.5
EXHAUST VALVE (DS–EXH07)	0.00	0.0	674520.0	1.0	1.0000	0.00	0.0	80174.0	1.0
MUFFLER (DS–EXH10)	0.00	0.0	674520.0	4.0	1.0000	0.00	0.0	80174.0	4.0
FUEL SYSTEM (DS–FLS)	0.91	9636.0	8225.9	2.1	0.9989	7.65	1145.3	977.7	2.1
DEAERATOR TANK (DS–FLS02)	0.00	0.0	674520.0	1.0	1.0000	0.00	0.0	80174.0	1.0
FUEL FILTER (DS–FLS03)	0.00	0.0	337260.0	1.0	1.0000	0.00	0.0	40087.0	1.0
GOVERNOR (DS–FLS04)	0.12	74946.7	67452.0	3.2	0.9997	0.98	8908.2	8017.4	3.2
PUMPS (DS–FLS06)	0.35	24982.2	21758.7	1.8	0.9999	2.95	2969.4	2586.3	1.8
VALVES (DS–FLS07)	0.01	674520.0	674520.0	1.5	1.0000	0.11	80174.0	80174.0	1.5
INJECTOR (DS–FLS08)	0.21	42157.5	39677.6	2.5	0.9994	1.75	5010.9	4716.1	2.5
FUEL LINE (DS–FLS09)	0.22	39677.6	37473.3	1.8	1.0000	1.86	4716.1	4454.1	1.8
FUEL OIL REGULATOR (DS–FLS10)	0.00	0.0	337260.0	2.0	1.0000	0.00	0.0	40087.0	2.0
GENERATOR (DS–GNR)	0.09	96360.0	74946.7	2.2	0.9999	0.76	11453.4	8908.2	2.2
GENERATOR (DS–GNR)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
BEARINGS (DS–GNR01)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
FIELD (DS–GNR05)	0.05	168630.0	112420.0	1.8	1.0000	0.44	20043.5	13362.3	1.8
FLYWHEEL (DS–GNR10)	0.04	224840.0	224840.0	3.0	1.0000	0.33	26724.7	26724.7	3.0
INSULATION (DS–GNR11)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
COLLECTOR RINGS (DS–GNR12)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
LUBE OIL/HYDRAULIC SYSTEM (DS–LBO)	0.25	35501.1	19272.0	2.5	0.9998	2.08	4219.7	2290.7	2.5
LUBE OIL/HYDRAULIC SYSTEM (DS–LBO)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
COOLER (DS–LBO02)	0.16	56210.0	56210.0	3.8	0.9999	1.31	6681.2	6681.2	3.8
FILTER (DS–LBO04)	0.00	0.0	74946.7	0.8	1.0000	0.00	0.0	8908.2	0.8
PIPING (DS–LBO06)	0.01	674520.0	337260.0	2.0	1.0000	0.11	80174.0	40087.0	2.0
STRAINER (DS–LBO10)	0.01	674520.0	134904.0	1.4	1.0000	0.11	80174.0	16034.8	1.4
LUBRICATOR (DS–LBO12)	0.06	134904.0	96360.0	3.3	1.0000	0.55	6034.8	11453.4	3.3
STARTING SYSTEM (DS–STS)	0.18	48180.0	17295.4	1.6	0.9999	1.53	5726.7	2055.7	1.6
AIR FILTER (DS–STS04)	0.00	0.0	26980.8	1.4	1.0000	0.00	0.0	3207.0	1.4
AIR CYLINDER (DS–STS05)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
STARTING AIR ELBOW (DS–STS06)	0.13	67452.0	67452.0	2.2	1.0000	1.09	8017.4	8017.4	2.2
AIR LINE (DS–STS07)	0.03	337260.0	337260.0	1.0	1.0000	0.22	40087.0	40087.0	1.0
VALVES (DS–STS08)	0.03	337260.0	337260.0	2.5	1.0000	0.22	40087.0	40087.0	2.5
GOVERNOR BOOSTER (DS–STS13)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0

TABLE VII
SUBSYSTEM AND COMPONENT RAM MEASURES FOR STABILITY AUXILIARY DIESELS

Equipment	Period Hours					Operating Hours			
	Failures per Year	MTBF (Hours)	MTBCM (Hours)	MTTCM (Hours)	Operational Availability	Failures per Year	MTBF (Hours)	MTBCM (Hours)	MTTCM (Hours)
CONTROL & INSTRUMENTATION (DS-CTI)	0.01	678900.0	452600.0	1.7	1.0000	0.05	161621.0	107747.3	1.7
CIRCUIT BREAKERS (DS-CTI01)	0.01	1357800.0	1357800.0	2.0	1.0000	0.03	323242.0	323242.0	2.0
GAUGES (DS-CTI03)	0.01	1357800.0	678900.0	1.5	1.0000	0.03	323242.0	161621.0	1.5
SWITCHES (DS-CTI04)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
COOLING WATER SYSTEM (DS-CWT)	0.05	193971.4	135780.0	1.8	1.0000	0.19	46177.4	32324.2	1.8
AIR COOLER (DS-CWT01)	0.01	1357800.0	1357800.0	1.0	1.0000	0.03	323242.0	323242.0	1.0
COOLING WATER PUMP (DS-CWT02)	0.01	678900.0	271560.0	1.8	1.0000	0.05	161621.0	64648.4	1.8
COOLING TOWERS (DS-CWT08)	0.01	1357800.0	1357800.0	2.0	1.0000	0.03	323242.0	323242.0	2.0
HEAT EXCHANGER (DS-CWT10)	0.02	452600.0	452600.0	1.8	1.0000	0.08	107747.3	107747.3	1.8
DIESEL ENGINE (DS-ENG)	0.64	13715.2	4437.3	3.8	0.9988	2.68	3265.1	1056.3	3.8
DIESEL ENGINE (DS-ENG)	0.01	1357800.0	1357800.0	0.0	0.9998	0.03	323242.0	323242.0	0.0
BEARINGS (DS-ENG01)	0.10	84862.5	38794.3	2.4	1.0000	0.43	20202.6	9235.5	2.4
CYLINDER (DS-ENG02)	0.05	193971.4	150866.7	2.8	1.0000	0.19	46177.4	35915.8	2.8
CYLINDER HEADS (DS-ENG03)	0.12	71463.2	52223.1	3.4	0.9999	0.51	17012.7	12432.4	3.4
PISTONS (DS-ENG06)	0.19	45260.0	9236.7	4.4	0.9992	0.81	10774.7	2198.9	4.4
VALVES (DS-ENG08)	0.01	1357800.0	271560.0	2.5	1.0000	0.03	323242.0	64648.4	2.5
RINGS (DS-ENG09)	0.15	59034.8	16972.5	3.6	0.9999	0.62	14054.0	4040.5	3.6
INTAKE MANIFOLD (DS-ENG11)	0.01	1357800.0	1357800.0	2.0	1.0000	0.03	323242.0	323242.0	2.0
CRANKCASE (DS-ENG12)	0.00	0.0	1357800.0	4.0	1.0000	0.00	0.0	323242.0	4.0
CAM (DS-ENG15)	0.01	1357800.0	1357800.0	8.0	1.0000	0.03	323242.0	323242.0	8.0
EXHAUST SYSTEM (DS-EXH)	0.03	339450.0	79870.6	1.9	0.9999	0.11	80810.5	19014.2	1.9
EXHAUST SYSTEM (DS-EXH)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
EXHAUST MANIFOLD (DS-EXH06)	0.00	0.0	1357800.0	2.0	1.0000	0.00	0.0	323242.0	2.0
EXHAUST VALVE (DS-EXH07)	0.02	52600.0	90520.0	1.9	1.0000	0.08	107747.3	21549.5	1.9
HEADER (DS-EXH09)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
MUFFLER (DS-EXH10)	0.01	1357800.0	1357800.0	1.5	1.0000	0.03	323242.0	323242.0	1.5
FUEL SYSTEM (DS-FLS)	0.41	21552.4	7339.5	2.7	0.9998	1.71	5130.8	1747.3	2.7
FUEL SYSTEM (DS-FLS)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
FUEL FILTER (DS-FLS03)	0.02	452600.0	21552.4	1.1	1.0000	0.08	107747.3	5130.8	1.1
GOVERNOR (DS-FLS04)	0.05	193971.4	169725.0	3.0	1.0000	0.19	6177.4	40405.2	3.0
PUMPS (DS-FLS06)	0.06	135780.0	113150.0	2.2	1.0000	0.27	32324.2	26936.8	2.2
INJECTOR (DS-FLS08)	0.25	35731.6	13997.9	3.7	0.9999	1.03	8506.4	3332.4	3.7
FUEL LINE (DS-FLS09)	0.03	271560.0	271560.0	2.6	1.0000	0.14	64648.4	64648.4	2.6
FUEL OIL REGULATOR (DS-FLS10)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
GENERATOR (DS-GNR)	0.06	135780.0	123436.4	2.3	1.0000	0.27	32324.2	29385.6	2.3
GENERATOR (DS-GNR)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
BEARINGS (DS-GNR01)	0.02	452600.0	339450.0	2.2	1.0000	0.08	107747.3	80810.5	2.2
FIELD (DS-GNR05)	0.04	226300.0	226300.0	2.2	1.0000	0.16	53873.7	53873.7	2.2
COLLECTOR RINGS (DS-GNR12)	0.01	1357800.0	1357800.0	3.0	1.0000	0.03	323242.0	323242.0	3.0
LUBE OIL/HYDRAULIC SYSTEM (DS-LBO)	0.06	135780.0	64657.1	1.2	0.9999	0.27	32324.2	15392.5	1.2
LUBE OIL/HYDRAULIC SYSTEM (DS-LBO)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
COOLER (DS-LBO02)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
FILTER (DS-LBO04)	0.01	1357800.0	113150.0	0.9	1.0000	0.03	323242.0	26936.8	0.9
PUMP (DS-LBO05)	0.05	193971.4	193971.4	1.6	1.0000	0.19	6177.4	46177.4	1.6
TANK (DS-LBO08)	0.01	1357800.0	1357800.0	2.0	1.0000	0.03	323242.0	323242.0	2.0
STRAINER (DS-LBO10)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
OIL SWITCH (DS-LBO14)	0.01	1357800.0	1357800.0	1.0	1.0000	0.03	323242.0	323242.0	1.0
STARTING SYSTEM (DS-STS)	0.02	452600.0	17407.7	1.0	1.0000	0.08	107747.3	4144.1	1.0
AIR FILTER (DS-STS04)	0.00	0.0	18104.0	1.0	1.0000	0.00	0.0	4309.9	1.0
VALVES (DS-STS08)	0.02	452600.0	452600.0	1.7	1.0000	0.08	107747.3	107747.3	1.7

TABLE VIII
SUBSYSTEM AND COMPONENT RAM MEASURES FOR CONTINUOUS-DUTY PACKAGE DIESELS

Equipment	Period Hours					Operating Hours			
	Failures per Year	MTBF (Hours)	MTBCM (Hours)	MTTCM (Hours)	Operational Availability	Failures per Year	MTBF (Hours)	MTBCM (Hours)	MTTCM (Hours)
BALANCE OF PLANT (DS-BOP)	0.02	407388.0	271592.0	0.3	1.0000	0.06	150349.0	100232.7	0.3
BALANCE OF PLANT (DS-BOP)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
COMBUSTION GAS MONITORING (DS-BOP01)	0.01	814776.0	814776.0	0.0	1.0000	0.03	300698.0	300698.0	0.0
ENCLOSURES (DS-BOP02)	0.00	0.0	814776.0	1.0	1.0000	0.00	0.0	300698.0	1.0
FIRE SUPPRESSION/DETECTION (DS-BOP03)	0.01	814776.0	814776.0	0.0	1.0000	0.03	300698.0	300698.0	0.0
CONTROL & INSTRUMENTATION (DS-CTI)	0.12	74070.5	28095.7	3.0	0.9999	0.32	27336.2	10368.9	3.0
CONTROL & INSTRUMENTATION (DS-CTI)	0.00	0.0	407388.0	1.5	1.0000	0.00	0.0	150349.0	1.5
CIRCUIT BREAKERS (DS-CTI01)	0.00	0.0	814776.0	1.0	1.0000	0.00	0.0	300698.0	1.0
ELECTRICAL MODULE (DS-CTI02)	0.04	203694.0	162955.2	4.5	1.0000	0.12	75174.5	60139.6	4.5
GAUGES (DS-CTI03)	0.04	203694.0	47928.0	1.2	1.0000	0.12	75174.5	17688.1	1.2
SWITCHES (DS-CTI04)	0.01	814776.0	407388.0	5.7	1.0000	0.03	300698.0	150349.0	5.7
WIRING (DS-CTI05)	0.02	407388.0	407388.0	14.0	1.0000	0.06	150349.0	150349.0	14.0
COOLING WATER SYSTEM (DS-CWT)	0.43	20369.4	10720.7	1.6	0.9998	1.17	7517.4	3956.6	1.6
COOLING WATER SYSTEM (DS-CWT)	0.01	814776.0	814776.0	5.6	1.0000	0.03	300698.0	300698.0	5.6
COOLING WATER PUMP (DS-CWT02)	0.13	67898.0	37035.3	2.2	0.9999	0.35	25058.2	13668.1	2.2
ENGINE COOLING (DS-CWT03)	0.22	40738.8	23964.0	1.2	0.9999	0.58	15034.9	8844.1	1.2
THERMOSTAT (DS-CWT05)	0.01	814776.0	162955.2	1.3	1.0000	0.03	300698.0	60139.6	1.3
TURBO CHARGER COOLING (DS-CWT06)	0.00	0.0	814776.0	2.0	1.0000	0.00	0.0	300698.0	2.0
VALVES (DS-CWT07)	0.01	814776.0	407388.0	1.5	1.0000	0.03	300698.0	150349.0	1.5
COOLING TOWERS (DS-CWT08)	0.01	814776.0	407388.0	1.0	1.0000	0.03	300698.0	150349.0	1.0
WATER LINE (DS-CWT09)	0.02	407388.0	135796.0	2.1	1.0000	0.06	150349.0	50116.3	2.1
HEAT EXCHANGER (DS-CWT10)	0.01	814776.0	814776.0	1.0	1.0000	0.03	300698.0	300698.0	1.0
WATER HEADER (DS-CWT12)	0.00	0.0	814776.0	2.0	1.0000	0.00	0.0	300698.0	2.0
WATER MANIFOLD (DS-CWT13)	0.01	814776.0	814776.0	1.0	1.0000	0.03	300698.0	300698.0	1.0
DIESEL ENGINE (DS-ENG)	1.91	4577.4	3409.1	8.5	0.9902	5.19	1689.3	1258.2	8.5
DIESEL ENGINE (DS-ENG)	0.04	203694.0	135796.0	9.7	0.9950	0.12	75174.5	50116.3	9.7
BEARINGS (DS-ENG01)	0.09	101847.0	81477.6	8.9	0.9999	0.23	37587.2	30069.8	8.9
CYLINDER (DS-ENG02)	0.30	29099.1	19399.4	4.3	0.9999	0.82	10739.2	7159.5	4.3
CYLINDER HEADS (DS-ENG03)	0.77	11316.3	10445.8	10.7	0.9968	2.10	4176.4	3855.1	10.7
DRIVE SHAFT (DS-ENG04)	0.02	407388.0	271592.0	30.0	0.9999	0.06	150349.0	100232.7	30.0
PISTONS (DS-ENG06)	0.22	40738.8	32591.0	2.9	0.9999	0.58	15034.9	12027.9	2.9
TURBO CHARGER (DS-ENG07)	0.14	62675.1	35425.0	3.6	0.9995	0.38	23130.6	13073.8	3.6
VALVES (DS-ENG08)	0.02	407388.0	203694.0	3.8	1.0000	0.06	150349.0	75174.5	3.8
RINGS (DS-ENG09)	0.04	203694.0	81477.6	8.3	1.0000	0.12	75174.5	30069.8	8.3
TIMING (DS-ENG10)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
INTAKE MANIFOLD (DS-ENG11)	0.05	162955.2	135796.0	9.9	0.9999	0.15	60139.6	50116.3	9.9
CRANKCASE (DS-ENG12)	0.10	90530.7	90530.7	5.6	0.9998	0.26	33410.9	33410.9	15.6
RODS (DS-ENG14)	0.02	407388.0	407388.0	21.5	0.9999	0.06	50349.0	150349.0	21.5
CAM (DS-ENG15)	0.08	116396.6	58198.3	14.1	0.9998	0.20	42956.9	21478.4	14.1
CHAIN DRIVE (DS-ENG17)	0.01	814776.0	407388.0	21.0	1.0000	0.03	300698.0	150349.0	21.0
TAPPET (DS-ENG18)	0.01	814776.0	162955.2	9.7	1.0000	0.03	300698.0	60139.6	9.7
EXHAUST SYSTEM (DS-EXH)	0.12	74070.5	40738.8	5.2	0.9997	0.32	27336.2	15034.9	5.2
EXHAUST SYSTEM (DS-EXH)	0.01	814776.0	407388.0	5.0	0.9998	0.03	300698.0	150349.0	5.0
EXHAUST DUCTING (DS-EXH01)	0.00	0.0	814776.0	2.0	1.0000	0.00	0.0	300698.0	2.0
EXPANSION JOINTS (DS-EXH03)	0.01	814776.0	203694.0	2.9	1.0000	0.03	300698.0	75174.5	2.9
EXHAUST MANIFOLD (DS-EXH06)	0.06	135796.0	116396.6	9.2	0.9999	0.17	50116.3	42956.9	9.2
EXHAUST VALVE (DS-EXH07)	0.03	271592.0	135796.0	2.8	1.0000	0.09	100232.7	50116.3	2.8
MUFFLER (DS-EXH10)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0

TABLE VIII (Continued)

Equipment	Period Hours: Failures per Year	Period Hours: MTBF (Hours)	Period Hours: MTBCM (Hours)	Period Hours: MTTCM (Hours)	Period Hours: Operational Availability	Operating Hours: Failures per Year	Operating Hours: MTBF (Hours)	Operating Hours: MTBCM (Hours)	Operating Hours: MTTCM (Hours)
FUEL SYSTEM (DS-FLS)	1.19	7340.3	3366.8	3.5	0.9992	3.23	2709.0	1242.6	3.5
FUEL SYSTEM (DS-FLS)	0.01	814776.0	814776.0	1.0	1.0000	0.03	300698.0	300698.0	1.0
DAY TANKS (DS-FLS01)	0.01	814776.0	203694.0	1.5	1.0000	0.03	300698.0	75174.5	1.5
FUEL FILTER (DS-FLS03)	0.02	407388.0	12730.9	1.2	1.0000	0.06	150349.0	4698.4	1.2
GOVERNOR (DS-FLS04)	0.27	32591.0	23279.3	5.5	0.9997	0.73	12027.9	8591.4	5.5
PUMPS (DS-FLS06)	0.24	37035.3	23279.3	3.3	0.9999	0.64	13668.1	8591.4	3.3
VALVES (DS-FLS07)	0.06	135796.0	101847.0	2.1	1.0000	0.17	50116.3	37587.2	2.1
INJECTOR (DS-FLS08)	0.40	22021.0	13357.0	6.0	0.9998	1.08	8127.0	4929.5	6.0
FUEL LINE (DS-FLS09)	0.18	47928.0	23964.0	2.1	0.9999	0.50	17688.1	8844.1	2.1
GEARBOX (DS-GBX)	0.01	814776.0	814776.0	12.0	1.0000	0.03	300698.0	300698.0	12.0
GEARBOX (DS-GBX)	0.01	814776.0	814776.0	12.0	1.0000	0.03	300698.0	300698.0	12.0
GENERATOR (DS-GNR)	0.09	101847.0	74070.5	7.7	0.9999	0.23	37587.2	27336.2	7.7
GENERATOR (DS-GNR)	0.04	203694.0	203694.0	18.9	0.9999	0.12	75174.5	75174.5	18.9
COOLING FANS (DS-GNR04)	0.00	0.0	0.0	10.0	1.0000	0.00	0.0	0.0	0.0
FIELD (DS-GNR05)	0.03	271592.0	203694.0	1.0	1.0000	0.09	100232.7	75174.5	1.0
FLYWHEEL (DS-GNR10)	0.01	814776.0	271592.0	1.8	1.0000	0.03	300698.0	100232.7	1.8
LUBE OIL/HYDRAULIC SYSTEM (DS-LBO)	0.30	29099.1	5580.7	2.0	0.9997	0.82	10739.2	2059.6	2.0
LUBE OIL/HYDRAULIC SYSTEM (DS-LBO)	0.00	0.0	814776.0	4.0	1.0000	0.00	0.0	300696.0	4.0
HEATER (DS-LBO01)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
COOLER (DS-LBO02)	0.01	814776.0	814776.0	74.2	0.9999	0.03	300698.0	300698.0	74.2
COOLER FAN (DS-LBO03)	0.01	814776.0	814776.0	2.0	1.0000	0.03	300698.0	300698.0	2.0
FILTER (DS-LBO04)	0.02	407388.0	8761.0	1.2	1.0000	0.06	150349.0	3233.3	1.2
PUMP (DS-LBO05)	0.12	74070.5	42882.9	1.7	0.9999	0.32	27336.2	15826.2	1.7
PIPING (DS-LBO06)	0.10	90530.7	40738.8	2.4	1.0000	0.26	33410.9	15034.9	2.4
TANK (DS-LBO08)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
VALVES (DS-LBO09)	0.02	407388.0	135796.0	1.5	1.0000	0.06	150349.0	50116.3	1.5
STRAINER (DS-LBO10)	0.02	407388.0	203694.0	1.2	1.0000	0.06	150349.0	75174.5	1.2
OIL SWITCH (DS-LBO14)	0.00	0.0	814776.0	1.0	1.0000	0.00	0.0	300698.0	1.0
STARTING SYSTEM (DS-STS)	0.19	45265.3	7686.6	1.6	0.9999	0.52	16705.4	2836.8	1.6
STARTING SYSTEM (DS-STS)	0.00	0.0	814776.0	2.5	1.0000	0.00	0.0	300698.0	2.5
STARTING AIR COMPRESSOR (DS-STS02)	0.03	271592.0	271592.0	4.2	1.0000	0.09	100232.7	100232.7	4.2
AIR FILTER (DS-STS04)	0.00	0.0	10720.7	1.3	1.0000	0.00	0.0	3956.6	1.3
STARTING AIR ELBOW (DS-STS06)	0.01	814776.0	814776.0	1.0	1.0000	0.03	300698.0	300698.0	1.0
AIR LINE (DS-STS07)	0.01	814776.0	814776.0	1.0	1.0000	0.03	300698.0	300698.0	1.0
VALVES (DS-STS08)	0.01	814776.0	407388.0	1.2	1.0000	0.03	300698.0	150349.0	1.2
AIR STARTS (DS-STS10)	0.12	74070.5	42882.9	2.5	1.0000	0.32	27336.2	15826.2	2.5
AIR INTAKE (DS-STS11)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
AIR DISTRIBUTOR (DS-STS12)	0.01	814776.0	814776.0	1.5	1.0000	0.03	300698.0	300698.0	1.5
BATTERY (DS-STS15)	0.00	0.0	407388.0	1.2	1.0000	0.00	0.0	150349.0	1.2

TABLE IX
SUBSYSTEM AND COMPONENT RAM MEASURES FOR STANDBY PACKAGE DIESELS

Equipment	Period Hours					Operating Hours			
	Failures per Year	MTBF (Hours)	MTBCM (Hours)	MTTCM (Hours)	Operational Availability	Failures per Year	MTBF (Hours)	MTBCM (Hours)	MTTCM (Hours)
CONTROL & INSTRUMENTATION (DS–CTI)	0.05	178099.0	152656.3	1.2	1.0000	0.82	10727.3	9194.9	1.2
CIRCUIT BREAKERS (DS–CTI01)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
GAUGES (DS–CTI03)	0.04	213718.8	178099.0	1.2	1.0000	0.68	12872.8	10727.3	1.2
THERMOCOUPLES (DS–CTI06)	0.01	1068594.0	1068594.0	1.0	1.0000	0.14	64364.0	64364.0	1.0
COOLING WATER SYSTEM (DS–CWT)	0.07	133574.2	56241.8	1.9	1.0000	1.09	8045.5	3387.6	1.9
COOLING WATER PUMP (DS–CWT02)	0.04	213718.8	89049.5	1.8	1.0000	0.68	12872.8	5363.7	1.8
ENGINE COOLING (DS–CWT03)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
VALVES (DS–CWT07)	0.00	0.0	1068594.0	1.0	1.0000	0.00	0.0	64364.0	1.0
COOLING TOWERS (DS–CWT08)	0.01	1068594.0	1068594.0	2.0	1.0000	0.14	64364.0	64364.0	2.0
WATER LINE (DS–CWT09)	0.01	1068594.0	534297.0	1.0	1.0000	0.14	64364.0	32182.0	1.0
HEAT EXCHANGER (DS–CWT10)	0.01	1068594.0	534297.0	5.0	1.0000	0.14	64364.0	32182.0	5.0
WATER HEADER (DS–CWT12)	0.00	0.0	1068594.0	1.0	1.0000	0.00	0.0	64364.0	1.0
DIESEL ENGINE (DS–ENG)	0.26	33393.6	18424.0	4.1	0.9995	4.36	2011.4	1109.7	4.1
DIESEL ENGINE (DS–ENG)	0.00	0.0	0.0	0.0	0.9997	0.00	0.0	0.0	0.0
BEARINGS (DS–ENG01)	0.01	1068594.0	213718.8	2.0	1.0000	0.14	64364.0	12872.8	2.0
CYLINDER (DS–ENG02)	0.05	178099.0	152656.3	2.3	1.0000	0.82	10727.3	9194.9	2.3
CYLINDER HEADS (DS–ENG03)	0.08	106859.4	62858.5	5.6	0.9999	1.36	6436.4	3786.1	5.6
PISTONS (DS–ENG06)	0.02	356198.0	178099.0	4.0	1.0000	0.41	21454.7	10727.3	4.0
TURBO CHARGER (DS–ENG07)	0.01	1068594.0	534297.0	6.0	1.0000	0.14	64364.0	32182.0	6.0
VALVES (DS–ENG08)	0.01	1068594.0	534297.0	3.0	1.0000	0.14	64364.0	32182.0	3.0
RINGS (DS–ENG09)	0.07	133574.2	97144.9	5.4	1.0000	1.09	8045.5	5851.3	5.4
TIMING (DS–ENG10)	0.00	0.0	1068594.0	1.0	1.0000	0.00	0.0	64364.0	1.0
INTAKE MANIFOLD (DS–ENG11)	0.00	0.0	534297.0	1.0	1.0000	0.00	0.0	32182.0	1.0
CRANKCASE (DS–ENG12)	0.01	1068594.0	356198.0	1.3	1.0000	0.14	64364.0	21454.7	1.3
RODS (DS–ENG14)	0.00	0.0	1068594.0	2.0	1.0000	0.00	0.0	64364.0	2.0
CAM (DS–ENG15)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
CHAIN DRIVE (DS–ENG17)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
TAPPET (DS–ENG18)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
ENGINE SWITCH GEAR (DS–ENG19)	0.01	1068594.0	1068594.0	5.0	1.0000	0.14	64364.0	64364.0	5.0
EXHAUST SYSTEM (DS–EXH)	0.02	356198.0	213718.8	1.8	1.0000	0.41	21454.7	12872.8	1.8
EXHAUST SYSTEM (DS–EXH)	0.02	534297.0	356198.0	1.7	1.0000	0.27	32182.0	21454.7	1.7
EXPANSION JOINTS (DS–EXH03)	0.01	1068594.0	1068594.0	3.0	1.0000	0.14	64364.0	64364.0	3.0
PORTS (DS–EXH05)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
EXHAUST MANIFOLD (DS–EXH06)	0.00	0.0	1068594.0	1.0	1.0000	0.00	0.0	64364.0	1.0
FUEL SYSTEM (DS–FLS)	0.24	36848.1	14841.6	2.3	0.9998	3.95	2219.4	893.9	2.3
FUEL SYSTEM (DS–FLS)	0.01	1068594.0	534297.0	1.0	1.0000	0.14	64364.0	32182.0	1.0
DAY TANKS (DS–FLS01)	0.01	1068594.0	1068594.0	1.0	1.0000	0.14	64364.0	64364.0	1.0
FUEL FILTER (DS–FLS03)	0.00	0.0	56241.8	1.0	1.0000	0.00	0.0	3387.6	1.0
GOVERNOR (DS–FLS04)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
PUMPS (DS–FLS06)	0.04	213718.8	178099.0	1.8	0.9999	0.68	12872.8	10727.3	1.8
VALVES (DS–FLS07)	0.03	267148.5	106859.4	2.1	1.0000	0.54	16091.0	6436.4	2.1
INJECTOR (DS–FLS08)	0.13	66787.1	38164.1	3.6	0.9999	2.18	4022.8	2298.7	3.6
FUEL LINE (DS–FLS09)	0.00	0.0	1068594.0	2.0	1.0000	0.00	0.0	64364.0	2.0
FUEL OIL REGULATOR (DS–FLS10)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
GAS JUMPER (DS–FLS11)	0.02	534297.0	213718.8	2.0	1.0000	0.27	32182.0	12872.8	2.0
GENERATOR (DS–GNR)	0.03	267148.5	213718.8	2.8	0.9987	0.54	16091.0	12872.8	2.8
GENERATOR (DS–GNR)	0.01	1068594.0	1068594.0	2.0	0.9987	0.14	64364.0	64364.0	2.0
FIELD (DS–GNR05)	0.02	356198.0	267148.5	3.0	1.0000	0.41	21454.7	16091.0	3.0
FLYWHEEL (DS–GNR10)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
LUBE OIL/HYDRAULIC SYSTEM (DS–LBO)	0.16	56241.8	20162.2	3.4	0.9998	2.59	3387.6	1214.4	3.4
LUBE OIL/HYDRAULIC SYSTEM (DS–LBO)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
HEATER (DS–LBO01)	0.05	178099.0	76328.1	1.9	1.0000	0.82	10727.3	4597.4	1.9
COOLER (DS–LBO02)	0.00	0.0	1068594.0	1.0	1.0000	0.00	0.0	64364.0	1.0
COOLER FAN (DS–LBO03)	0.01	1068594.0	1068594.0	15.0	1.0000	0.14	64364.0	64364.0	15.0
FILTER (DS–LBO04)	0.02	356198.0	56241.8	5.4	0.9999	0.41	21454.7	3387.6	5.4
PUMP (DS–LBO05)	0.02	356198.0	133574.2	1.9	1.0000	0.41	21454.7	8045.5	1.9
PIPING (DS–LBO06)	0.01	1068594.0	1068594.0	8.0	1.0000	0.14	64364.0	64364.0	8.0
TANK (DS–LBO08)	0.01	1068594.0	1068594.0	2.0	1.0000	0.14	64364.0	64364.0	2.0
VALVES (DS–LBO09)	0.01	1068594.0	1068594.0	2.0	1.0000	0.14	64364.0	64364.0	2.0
STRAINER (DS–LBO10)	0.02	534297.0	356198.0	1.7	1.0000	0.27	32182.0	21454.7	1.7
LUBRICATOR (DS–LBO12)	0.01	1068594.0	267148.5	1.2	1.0000	0.14	64364.0	16091.0	1.2
STARTING SYSTEM (DS–STS)	0.14	62858.5	44524.8	2.6	0.9999	2.31	3786.1	2681.8	2.6
STARTING SYSTEM (DS–STS)	0.02	534297.0	534297.0	2.5	1.0000	0.27	32182.0	32182.0	2.5
STARTING AIR COMPRESSOR (DS–STS02)	0.02	356198.0	356198.0	6.7	1.0000	0.41	21454.7	21454.7	6.7
AIR FILTER (DS–STS04)	0.00	0.0	1068594.0	1.0	1.0000	0.00	0.0	64364.0	1.0
VALVES (DS–STS08)	0.01	1068594.0	534297.0	3.0	1.0000	0.14	64364.0	32182.0	3.0
AIR STARTS (DS–STS10)	0.07	133574.2	89049.5	2.0	1.0000	1.09	8045.5	5363.7	2.0
AIR INTAKE (DS–STS11)	0.00	0.0	1068594.0	1.0	1.0000	0.00	0.0	64364.0	1.0
BATTERY (DS–STS15)	0.02	356198.0	356198.0	2.0	1.0000	0.41	21454.7	21454.7	2.0

TABLE X
SUBSYSTEM AND COMPONENT RAM MEASURES FOR CONTINUOUS-DUTY GAS TURBINES

Equipment	Period Hours					Operating Hours			
	Failures per Year	MTBF (Hours)	MTBCM (Hours)	MTTCM (Hours)	Operational Availability	Failures per Year	MTBF (Hours)	MTBCM (Hours)	MTTCM (Hours)
AIR INTAKE SYSTEM (GT-AIS)	0.00	0.0	47698.3	8.6	1.0000	0.00	0.0	29148.1	8.6
AIR INLET FILTER (GT-AIS01)	0.00	0.0	55648.0	2.0	1.0000	0.00	0.0	34006.2	2.0
DUCTING (GT-AIS03)	0.00	0.0	333888.0	48.0	1.0000	0.00	0.0	204037.0	48.0
BALANCE OF PLANT (GT-BOP)	0.05	166944.0	83472.0	2.3	0.9907	0.09	102018.5	51009.2	2.3
FIRE SUPPRESSION/DETECTION (GT-BOP03)	0.05	166944.0	83472.0	2.3	1.0000	0.09	102018.5	51009.2	2.3
TESTING (GT-BOP04)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
CLEANING (GT-BOP05)	0.00	0.0	0.0	0.0	0.9990	0.00	0.0	0.0	0.0
INSPECTION (GT-BOP06)	0.00	0.0	0.0	0.0	0.9918	0.00	0.0	0.0	0.0
COMBUSTION SYSTEM (GT-CMB)	0.21	41736.0	23849.1	1.5	0.9999	0.34	25504.6	14574.1	1.5
COMBUSTION SYSTEM (GT-CMB)	0.08	111296.0	111296.0	1.3	1.0000	0.13	68012.3	68012.3	1.3
FUEL NOZZLES (GT-CMB02)	0.13	66777.6	30353.5	1.6	1.0000	0.21	40807.4	18548.8	1.6
COMPRESSOR (GT-CMP)	0.10	83472.0	47698.3	1.1	1.0000	0.17	51009.2	29148.1	1.1
FLEXLINE (GT-CMP05)	0.00	0.0	333888.0	1.0	1.0000	0.00	0.0	204037.0	1.0
BLEEDVALVE (GT-CMP06)	0.10	83472.0	55648.0	1.2	1.0000	0.17	51009.2	34006.2	1.2
CONTROL & INSTRUMENTATION (GT-CTI)	0.63	13912.0	9274.7	1.2	0.9999	1.03	8501.5	5667.7	1.2
CONTROL & INSTRUMENTATION (GT-CTI)	0.03	333888.0	333888.0	1.0	1.0000	0.04	204037.0	204037.0	1.0
CIRCUIT BREAKERS (GT-CTI01)	0.05	166944.0	166944.0	1.0	1.0000	0.09	102018.5	102018.5	1.0
ELECTRICAL MODULE (GT-CTI02)	0.31	27824.0	23849.1	1.5	0.9999	0.52	17003.1	14574.1	1.5
GAUGES (GT-CTI03)	0.05	166944.0	37098.7	0.8	1.0000	0.09	102018.5	22670.8	0.8
SWITCHES (GT-CTI04)	0.16	55648.0	41736.0	1.1	1.0000	0.26	34006.2	25504.6	1.1
THERMOCOUPLE (GT-CTI07)	0.03	333888.0	166944.0	2.0	1.0000	0.04	204037.0	102018.5	2.0
EXHAUST SYSTEM (GT-EXH)	0.00	0.0	333888.0	1.0	1.0000	0.00	0.0	204037.0	1.0
EXHAUST FAN (GT-EXH03)	0.00	0.0	333888.0	1.0	1.0000	0.00	0.0	204037.0	1.0
FUEL SYSTEM (GT-FLS)	1.89	4637.3	3442.1	3.0	0.9992	3.09	2833.8	2103.5	3.0
FUEL SYSTEM (GT-FLS)	0.08	111296.0	111296.0	1.5	1.0000	0.13	68012.3	68012.3	1.5
AIR MANIFOLD (GT-FLS01)	0.00	0.0	333888.0	2.0	1.0000	0.00	0.0	204037.0	2.0
BOOST PUMP (GT-FLS02)	0.13	66777.6	66777.6	2.2	1.0000	0.21	40807.4	40807.4	2.2
FILTERS (GT-FLS04)	0.10	83472.0	55648.0	1.8	1.0000	0.17	51009.2	34006.2	1.8
GAS MANIFOLD (GT-FLS06)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
GOVERNOR (GT-FLS07)	0.60	14516.9	10770.6	5.9	0.9995	0.99	8871.2	6581.8	5.9
MAIN FUEL PUMP (GT-FLS08)	0.10	83472.0	66777.6	1.6	1.0000	0.17	51009.2	40807.4	1.6
ORIFICE (GT-FLS10)	0.03	333888.0	166944.0	2.0	1.0000	0.04	204037.0	102018.5	2.0
PRESSURE GAUGE (GT-FLS12)	0.03	333888.0	333888.0	1.0	1.0000	0.04	204037.0	204037.0	1.0
STRAINER (GT-FLS13)	0.05	166944.0	83472.0	1.2	1.0000	0.09	102018.5	51009.2	1.2
VALVES (GT-FLS14)	0.39	22259.2	16694.4	1.5	0.9999	0.64	13602.5	10201.9	1.5
PIPING (GT-FLS15)	0.18	47698.3	33388.8	2.6	0.9999	0.30	29148.1	20403.7	2.6
SEALS (GT-FLS16)	0.16	55648.0	47698.3	1.1	1.0000	0.26	34006.2	29148.1	1.1
FLOW METER (GT-FLS17)	0.03	333888.0	166944.0	1.0	1.0000	0.04	204037.0	102018.5	1.0
GEARBOX (GT-GBX)	0.03	333888.0	166944.0	1.5	1.0000	0.04	204037.0	102018.5	1.5
GEARBOX (GT-GBX)	0.00	0.0	333888.0	2.0	1.0000	0.00	0.0	204037.0	2.0
SEALS (GT-GBX04)	0.03	333888.0	333888.0	1.0	1.0000	0.04	204037.0	204037.0	1.0
GENERATOR (GT-GNR)	0.13	66777.6	41736.0	4.1	0.9999	0.21	40807.4	25504.6	4.1
GENERATOR (GT-GNR)	0.00	0.0	333888.0	8.0	1.0000	0.00	0.0	204037.0	8.0
BEARINGS (GT-GNR01)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
FIELD (GT-GNR05)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
STATOR (GT-GNR09)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
TURBINE COUPLING (GT-GNR10)	0.05	166944.0	83472.0	2.8	1.0000	0.09	102018.5	51009.2	2.8
VOLTAGE REGULATOR (GT-GNR11)	0.08	111296.0	111296.0	4.7	1.0000	0.13	68012.3	68012.3	4.7
LUBE OIL/HYDRAULIC SYSTEM (GT-LBO)	0.71	12366.2	8347.2	1.8	0.9998	1.16	7556.9	5100.9	1.8
AIR-TO-OIL COOLER (GT-LBO01)	0.13	66777.6	66777.6	2.3	0.9999	0.21	40807.4	40807.4	2.3
HYDRAULIC PUMP (GT-LBO02)	0.05	166944.0	166944.0	2.0	1.0000	0.09	102018.5	102018.5	2.0
LUBE OIL FILTER (GT-LBO03)	0.08	111296.0	30353.5	1.9	1.0000	0.13	68012.3	18548.8	1.9
OIL COOLER FAN (GT-LBO05)	0.08	111296.0	83472.0	2.0	1.0000	0.13	68012.3	51009.2	2.0
OIL MANIFOLDS (GT-LBO06)	0.03	333888.0	333888.0	1.0	1.0000	0.04	204037.0	204037.0	1.0
OIL TANK (GT-LBO07)	0.05	166944.0	166944.0	1.0	1.0000	0.09	102018.5	102018.5	1.0
PRE LUBE OIL PUMP (GT-LBO09)	0.10	83472.0	83472.0	2.6	1.0000	0.17	51009.2	51009.2	2.6
PIPING (GT-LBO12)	0.10	83472.0	55648.0	1.1	1.0000	0.17	51009.2	34006.2	1.1
SEALS (GT-LBO13)	0.03	333888.0	111296.0	1.0	1.0000	0.04	204037.0	68012.3	1.0
PRECIPITATOR (GT-LBO14)	0.05	166944.0	166944.0	2.5	1.0000	0.09	102018.5	102018.5	2.5
REDUCTION GEARBOX (GT-RGB)	0.03	333888.0	333888.0	2.0	1.0000	0.04	204037.0	204037.0	2.0
REDUCTION GEARBOX (GT-RGB)	0.03	333888.0	333888.0	2.0	1.0000	0.04	204037.0	204037.0	2.0

TABLE X (Continued)

Equipment	Period Hours: Failures per Year	Period Hours: MTBF (Hours)	Period Hours: MTBCM (Hours)	Period Hours: MTTCM (Hours)	Period Hours: Operational Availability	Operating Hours: Failures per Year	Operating Hours: MTBF (Hours)	Operating Hours: MTBCM (Hours)	Operating Hours: MTTCM (Hours)
STARTING SYSTEM (GT-STS)	0.71	12366.2	9820.2	19.5	0.9980	1.16	7556.9	6001.1	19.5
STARTING SYSTEM (GT-STS)	0.08	111296.0	111296.0	0.7	1.0000	0.13	68012.3	68012.3	0.7
AIR PUMP (GT-STS01)	0.03	333888.0	111296.0	2.3	1.0000	0.04	204037.0	68012.3	2.3
FILTER (GT-STS02)	0.03	333888.0	333888.0	1.0	1.0000	0.04	204037.0	204037.0	1.0
REGULATOR (GT-STS03)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
BATTERY (GT-STS06)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
STARTING SHAFT (GT-STS07)	0.03	333888.0	333888.0	2.0	1.0000	0.04	204037.0	204037.0	2.0
STARTER MOTOR (GT-STS08)	0.13	66777.6	47698.3	83.6	0.9982	0.21	40807.4	29148.1	83.6
GARLOC SEAL (GT-STS11)	0.42	20868.0	17573.1	3.5	0.9998	0.69	12752.3	10738.8	3.5
TURBINE (GT-TRB)	0.08	111296.0	166944.0	121.0	0.9954	0.13	68012.3	102018.5	121.0
TURBINE (GT-TRB)	0.05	166944.0	333888.0	240.0	0.9954	0.09	102018.5	204037.0	240.0
CASING (GT-TRB02)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
BEARING (GT-TRB05)	0.03	333888.0	333888.0	2.0	1.0000	0.04	204037.0	204037.0	2.0

TABLE XI
SUBSYSTEM AND COMPONENT RAM MEASURES FOR STANDBY GAS TURBINES

Equipment	Period Hours: Failures per Year	Period Hours: MTBF (Hours)	Period Hours: MTBCM (Hours)	Period Hours: MTTCM (Hours)	Period Hours: Operational Availability	Operating Hours: Failures per Year	Operating Hours: MTBF (Hours)	Operating Hours: MTBCM (Hours)	Operating Hours: MTTCM (Hours)
AIR INTAKE SYSTEM (GT-AIS)	0.01	975612.0	975612.0	1.0	1.0000	1.29	6795.5	6795.5	1.0
DUMPERS (GT-AIS04)	0.01	975612.0	975612.0	1.0	1.0000	1.29	6795.5	6795.5	1.0
BALANCE OF PLANT (GT-BOP)	0.00	0.0	0.0	0.0	0.9989	0.00	0.0	0.0	0.0
TESTING (GT-BOP04)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
CLEANING (GT-BOP05)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
INSPECTION (GT-BOP06)	0.00	0.0	0.0	0.0	0.9989	0.00	0.0	0.0	0.0
COMBUSTION SYSTEM (GT-CMB)	0.00	1951224.0	1951224.0	4.0	1.0000	0.64	13591.0	13591.0	4.0
FUEL NOZZLES (GT-CMB02)	0.00	1951224.0	1951224.0	4.0	1.0000	0.64	13591.0	13591.0	4.0
CONTROL & INSTRUMENTATION (GT-CTI)	0.04	216802.7	150094.2	8.3	0.9999	5.80	1510.1	1045.5	8.3
CONTROL & INSTRUMENTATION (GT-CTI)	0.00	1951224.0	1951224.0	1.0	1.0000	0.64	13591.0	13591.0	1.0
CIRCUIT BREAKERS (GT-CTI01)	0.00	0.0	1951224.0	0.5	1.0000	0.00	0.0	13591.0	0.5
ELECTRICAL MODULE (GT-CTI02)	0.02	487806.0	325204.0	7.2	1.0000	2.58	3397.8	2265.2	7.2
GAUGES (GT-CTI03)	0.00	1951224.0	975612.0	1.0	1.0000	0.64	13591.0	6795.5	1.0
SWITCHES (GT-CTI04)	0.01	975612.0	975612.0	29.0	1.0000	1.29	6795.5	6795.5	29.0
WIRING (GT-CTI05)	0.00	1951224.0	1951224.0	4.0	1.0000	0.64	13591.0	13591.0	4.0
EXHAUST SYSTEM (GT-EXH)	0.00	1951224.0	975612.0	5.5	1.0000	0.64	13591.0	6795.5	5.5
EXHAUST DUCTING (GT-EXH01)	0.00	0.0	1951224.0	1.0	1.0000	0.00	0.0	13591.0	1.0
EXHAUST FAN (GT-EXH03)	0.00	1951224.0	1951224.0	10.0	1.0000	0.64	13591.0	13591.0	10.0
FUEL SYSTEM (GT-FLS)	0.04	243903.0	130081.6	5.0	1.0000	5.16	1698.9	906.1	5.0
BOOST PUMP (GT-FLS02)	0.01	650408.0	650408.0	2.0	1.0000	1.93	4530.3	4530.3	2.0
FILTERS (GT-FLS04)	0.00	1951224.0	278746.3	1.1	1.0000	0.64	13591.0	1941.6	1.1
GOVERNOR (GT-FLS07)	0.00	1951224.0	1951224.0	2.0	1.0000	0.64	13591.0	13591.0	2.0
MAIN FUEL PUMP (GT-FLS08)	0.00	1951224.0	1951224.0	4.0	1.0000	0.64	13591.0	13591.0	4.0
STRAINER (GT-FLS13)	0.00	0.0	0.0	0.0	1.0000	0.00	0.0	0.0	0.0
VALVES (GT-FLS14)	0.01	975612.0	975612.0	27.5	1.0000	1.29	6795.5	6795.5	27.5
PIPING (GT-FLS15)	0.00	0.0	1951224.0	1.0	1.0000	0.00	0.0	13591.0	1.0
GENERATOR (GT-GNR)	0.04	216802.7	216802.7	33.3	0.9998	5.80	1510.1	1510.1	33.3
GENERATOR (GT-GNR)	0.00	1951224.0	1951224.0	72.0	1.0000	0.64	13591.0	13591.0	72.0
TURBINE COUPLING (GT-GNR10)	0.03	278746.3	278746.3	32.2	0.9999	4.51	1941.6	1941.6	32.2
VOLTAGE REGULATOR (GT-GNR11)	0.00	1951224.0	1951224.0	2.0	1.0000	0.64	13591.0	13591.0	2.0
LUBE OIL/HYDRAULIC SYSTEM (GT-LBO)	0.02	390244.8	177384.0	1.6	1.0000	3.22	2718.2	1235.5	1.6
LUBE OIL FILTER (GT-LBO03)	0.00	0.0	650408.0	2.0	1.0000	0.00	0.0	4530.3	2.0
VALVES (GT-LBO11)	0.00	0.0	1951224.0	1.0	1.0000	0.00	0.0	13591.0	1.0
PIPING (GT-LBO12)	0.02	487806.0	487806.0	1.8	1.0000	2.58	3397.8	3397.8	1.8
SEALS (GT-LBO13)	0.00	1951224.0	650408.0	1.3	1.0000	0.64	13591.0	4530.3	1.3
REDUCTION GEARBOX (GT-RGB)	0.00	1951224.0	1951224.0	360.0	0.9998	0.64	13591.0	13591.0	360.0
REDUCTION GEARBOX (GT-RGB)	0.00	1951224.0	1951224.0	360.0	0.9998	0.64	13591.0	13591.0	360.0
STARTING SYSTEM (GT-STS)	0.13	67283.6	45377.3	28.6	0.9994	18.69	468.7	316.1	28.6
STARTING SYSTEM (GT-STS)	0.00	1951224.0	1951224.0	2.0	1.0000	0.64	13591.0	13591.0	2.0
BATTERY (GT-STS06)	0.08	108401.3	60975.8	3.3	1.0000	11.60	755.1	424.7	3.3
STARTING SHAFT (GT-STS07)	0.02	390244.8	390244.8	93.5	0.9998	3.22	2718.2	2718.2	93.5
STARTER MOTOR (GT-STS08)	0.02	390244.8	390244.8	130.8	0.9997	3.22	2718.2	2718.2	130.8
TURBINE (GT-TRB)	0.02	390244.8	390244.8	1158.4	0.9970	3.22	2718.2	2718.2	1158.4
TURBINE (GT-TRB)	0.02	487806.0	487806.0	1398.0	0.9971	2.58	3397.8	3397.8	1398.0
BEARING (GT-TRB05)	0.00	1951224.0	1951224.0	200.0	0.9999	0.64	13591.0	13591.0	200.0

Discussion

R. H. Gauger (Holmes & Narver): This is an excellent survey and is the most comprehensive one available for the 600–1800-kW size range of diesel and gas-turbine-generating units. The results are not what I would have expected, and users of these data should be altered to differing results from surveys made by others. I have made a number of surveys of the reliability of diesel and gas-turbine-generating units of various sizes and will be making a comparison of the results with this new survey.

L. D. Monaghan (Hartford Steam Boiler Inspection and Insurance Company): My comments are directed at the corrective maintenance category. The corrective maintenance code should indicate why the corrective maintenance was necessary. The cause should address such things as lack of preventive maintenance or a manufacturer's defect. Knowing the reason for the maintenance would help the user of these data to differentiate between a manufacturing problem and an operational problem. Another suggestion is for the maintenance category to be subdivided into routine, preventive, and lack of maintenance.

Richard H. McFadden, Peter L. Appignani, and Gary DeMoss (Science Applications International Corporation): This paper represents a significant new base of reliability data for the most popular types of small generating units and will be a valuable resource for intelligent decisions between diesel- and gas-turbine-powered generation. The authors' component coding approach is excellent and would be a good basis for a standardized "component taxonomy" for diesel and gas-turbine generators.

The paper raises some questions for which answers would be valuable to system and reliability engineers contemplating similar projects, and we would appreciate the authors' comments on them.

First, as the authors remark, failure to start is the predominant failure mode of units of both types in "standby" service. (Independently developed reliability statistics on both nuclear-plant standby diesels and utility peaking gas turbines tend to confirm this observation.) As the authors also imply, the distinction between standby and continuous service is blurred in the industrial-commercial environment, because even the sets in nominally "continuous" duty typically operate cyclically, with many more starts than a base-loaded generating unit. Since starting reliability seems to be a critical RAM parameter, why are failure rates calculated exclusively in terms of failures per unit-year rather than failures per demand? The level of detail of the failure analysis in the paper suggests that the raw data were sufficient to distinguish between time- and demand-related failures and allow both failure rate per-unit time and failure-probability per demand to be calculated.

Second, although the RAM data were not conclusive and judgments about the relative merits of diesels versus gas turbines probably were outside the scope of this study, did the authors develop any insights into the optimum selection for various industrial, commercial building, and institutional applications?

P. F. Albrecht (General Electric Company): A key parameter for standby units is starting reliability. The text mentions starting reliability but does not give any statistics. I cannot determine how starting failures were treated. I assume they were counted as forced outages.

Another important event is "failed while not running." This is not discussed at all. These could be failures discovered by periodic testing or inspection. Thus, test frequency may be a very important parameter in determining operating availability. It does not appear that this factor was considered in the survey.

Basically, the authors have analyzed the data using a conventional two-state model approach. They have expressed results on both a period-hour and operating-hour base to suit a "variety of applications." In fact, a two-state model is not very useful for standby units, and the results presented are therefore difficult to use.

Pat O'Donnell (El Paso Natural Gas Company): The reliability survey data on diesel and gas-turbine generators collected by ARINC Research Corporation appear to provide an excellent data base for meaningful reliability studies on important equipment types. The results reflect an obvious intense and praiseworthy effort in assembling a well-organized and complete data base for its intended purpose. Personal plant visits, as reported in the paper, especially add to the credibility of the results. Although particular details on applications and circumstances of use are not listed, the number of plants, the number of power systems, periods of time, and the number of events counted are impressive and reflect very credible results.

As with any reliability survey, a given set of results always leads to questions and concerns related to any user's given experience background, and usually further manipulation and analysis of the data are required. My intent is to point out some questions and concerns that, hopefully, will lead to additional analyses. In many industries, economic studies comparing gas turbine/generators with reciprocating engine/generators are usually straightforward and simple, with the exception of reliability comparisons and the effects of reliability on economics. Hopefully, these new data will add a missing link and allow more meaningful and accurate comparisons to be made.

An important concern in evaluating the categories surveyed is the speed of the diesel engine. Typically, continuous duty units are designed and applied to run at slower speeds than standby units. "High-speed" reciprocating engines (e.g., 1200 r/min and higher) require frequent maintenance and predictable repair downtime compared with slow-speed units that simply do not experience the same mechanical stress. One would expect a higher failure rate or higher frequency or maintenance, or both, for high-speed engines than for slower speed engines. Will the data allow speed ranges to be identified and corresponding reliability comparisons to be made?

Starting reliability is an important concern, especially for standby or emergency applications. It is unclear if the failures shown for "starting systems" also mean "failures to start." The data might, in some cases, reflect component failures even though the generator set successfully started. Actual "failures to start" would be beneficial in comparing diesel engines with gas turbines, since there are many who believe there is a significant difference. Whether a unit is locally or remotely started normally requires an assessment of reliability in starting. The impact of a failure to start is obviously different when personnel are on site to address a problem immediately as compared with when personnel must travel to a site to address a problem.

Another concern that is important to reliability is the type of starter used. It appears from the data presented here that air and electric motors are two types of starters used. In the natural gas industry, expansion gas turbines are commonly used for starting turbines and definitely are much more reliable than electric starters, primarily because of the available gas supply. Can a closer analysis be made comparing the air systems with the electric motors?

Also regarding starting, the results reflect significant difference in failure rates between "continuous" and "standby" diesel units and "continuous" and "standby" gas turbines and state that this may be related to differences in actual in-use hours. One would also expect that the frequency of starting is different and might impact failure rates. Can this analysis be made?

The fuel system appears to be a significant contributor to failures. It is interesting that on "continuous" gas turbines, the fuel system is the least reliable part of the package. It would be beneficial if reasons could be identified. Are different types of fuels involved? If so, will the data collected allow comparing failure rates for each type?

The tabulated results in Appendix II, Tables VIII and IX, of the report suggest that possibly not all diesel units are truly packaged type (e.g., cooling towers, water heater). Can the data be refined further to identify which units are truly self-contained?

A last point of concern regards maintenance. A reciprocating engine is expected to be more demanding in routine maintenance requirements than a gas turbine. To qualify this statement, this is to say that it is easier to leave a gas turbine unattended, once it is running, than it is a reciprocating engine, especially if they are running continuously. There are various reasons why, some of which are the way the units are typically instrumented for protection and the number of moving parts and wear. If the MTBCM data include scheduled maintenance cycles, a comparison of failure rates for different cycles would be meaningful.

The results here reflect an excellent collection of data and should be very beneficial in making comparisons of these equipment types. In the application of reliability data an inevitable concern is the reason for differences in reliability between equipment types and applications. One obvious practical benefit is to be able to identify what corrective actions are encouraged by

TABLE XII
COMPARISON OF DIESEL AND GAS-TURBINE STARTING RELIABILITY STUDIES

Source	Number of Units	Start Attempts	Failed Starts	Starting Reliability
Gas-Turbine Starting Reliability Studies				
ARINC Research Corporation[1]	7	3,555	17	0.9952
Booz, Allen & Hamilton[2]	34	12,316	80	0.9935
Kongsberg Dresser Power[3]	38	17,749	141	0.9921
AT&T[4]	28	13,644	106	0.9922
Diesel Starting Reliability Studies				
ARINC Research Corporation[1]	—	—	—	0.97
Electric Power Research Institute (EPRI)[5]	155	22,320	83	0.9963
Consumers Power Company—Big Rock Point[6]	2	669	12	0.9821
Northeast Utilities—Millstone[6]	3	652	3	0.9954
Northeast Utilities—Connecticut Yankee[6]	2	642	2	0.9969
Commonwealth Edison Company—Zion[6]	4	1,693	30	0.9823
Consolidated Edison Company of New York, Inc.—Indian Point[6]	6	424	4	0.9906
Institute of Nuclear Power Operations (INPO)[7]	←	Data not available	→	0.9120
EPRI[8]	←	Data not available	→	0.9829

[1]ARINC Research Corporation. *Final Report—RAM Study of Diesel and Gas-Turbine Generator Sets*. Publication 4219-03-01-4803, October 1988.

[2]Booz, Allen Applied Research. *Small Gas Turbine Start Investigation*. April 1970.

[3]Kongsberg Dresser Power. Internal Study Comparing Diesels with Gas-Turbine Engines (unpublished), 1984.

[4]AT&T. Internal Study for Gas-Turbine Reliability (unpublished), 1980.

[5]Electric Power Research Institute. *Reliability of Emergency Diesel Generators at U.S. Nuclear Power Plants*. NSAC 108, September 1986.

[6]U.S. Nuclear Regulatory Commission. *Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR)*. NUREG/CR-4639 EGG-2458, Volume 5, RX, June 1988.

[7]Institute of Nuclear Power Operations. *Nuclear Plant Reliability Data System, 1982 Annual Report*, 1983.

[8]Electric Power Research Institute. *Diesel Power Reliability at Nuclear Power Plants: Data Preliminary Analysis*. NP-2433, June 1982.

a user and which are encouraged by a manufacturer. Hopefully, additional analyses will be made addressing the concerns of this discussion and other similar concerns stimulated by the results presented here.

Closure

The authors appreciate the thorough review and the many constructive comments and recommendations offered in the preceding discussion. While space limitations prohibit addressing all of the suggestions offered, a response to some of the more frequently cited comments is provided in the following paragraphs.

Obtaining data on unit starting reliability was one of the objectives of the study. However, most of the plants surveyed did not record data necessary to determine starting reliability. While it was often possible to identify start failures through interpretation of the maintenance event descriptions, the number of start attempts was typically not retrievable. In addition, our discussions with plant personnel indicated that many start failures were corrected through minor adjustments that were usually not documented in maintenance or operating records. Because of the limited data available, starting reliability statistics were not presented in the paper.

Some information on starting reliability was obtained during the study. These data are presented in Table XII. Seven gas-turbine units provided data on start attempts and start failures during periodic testing. To obtain estimates of diesel starting reliability, we surveyed plant managers of four of the standby diesel plants to estimate the number of start failures in 100 attempts. We then averaged these estimates to obtain an estimated diesel starting reliability. Table XII also shows a comparison of values for diesel and gas-turbine starting reliability.

With regard to maintenance, data were categorized on the basis of the nature of the individual maintenance task performed for each event. The maintenance codes do not refer to the cause of failure or the overall maintenance program for the plant. Additional reduction and analysis of the collected data would be required to investigate these issues.

An important feature of the computerized data base developed in this survey is the ability to sort and arrange the data to analyze specific issues regarding plant configuration, design, or operation. The preceding discussions have provided several beneficial suggestions for additional analyses. The results of additional data analyses or data collection activities under this program will be discussed in subsequent papers.

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Clayton A. Smith received the B.S. degree in aerospace engineering from the University of Maryland, College Park.

He is a Staff Engineer for ARINC Research Corporation. He is responsible for the development of data bases for many reliability, availability, and maintainability projects, including those for the Electric Power Research Institute (EPRI), the Gas Research Institute (GRI), petroleum refineries, electric utilities, and the Army Corps of Engineers. He also conducts analyses to investigate component criticality, cost optimization, and modification evaluations.

Michael D. Donovan (A'86) received the B.S. degree in mechanical engineering from Vanderbilt University, Nashville, TN, and the M.S. degree in industrial management from the Georgia Institute of Technology, Atlanta.

He is the Manager of the Industrial Process Group of ARINC Research Corporation and is responsible for the company's engineering services to clients in energy, petrochemical, and manufacturing industries.

Mr. Donovan is Chairman of Station Operations for the Energy Development and Power Generation Committee of the Power Engineering Society and is a Registered Professional Industrial Engineer in the State of Georgia.

Michael J. Bartos received the B.S. degree in mechanical engineering from Pennsylvania State University, University Park, in 1985.

He is currently a Mechanical Engineer in the Power Reliability Enhancement Program (PREP) with the U.S. Army Corps of Engineers, Engineering and Housing Support Center (EHSC). He has been with the PREP program since 1987. His experience with the program includes engineering support for operating power plants and efforts to enhance reliability, survivability, and operation/maintenance of critical command, control, communications, and intelligence facilities and utilities. He was with the U.S. Navy's Cruise Missile Branch of the Airborne Weapons Engineering Division where he served as a Project Engineer from 1985. His experience in the area was design verification, lot acceptance tests, and maintenance concerns. He is also involved in tutorial disadvantaged youth in the Washington, DC, area.