Appendix D Initial Type Test Procedure

D.1.0 Detailed Test Procedure

D.2.0 Recorded Parameter List

Table D.2.0-1 Parameters to be Monitored During Initial Type Test

Table D.2.0-2 Parameters to be Monitored During Seismic Test

Appendix E Hot/Cold Starting Comparison

E.1.0 PRIME MOVER COMPARISON

E.1.1 Diesel Generator (DG)

As shown in Figure E.1.1-1, DGs consist of a crankshaft producing a rotary motion and a piston producing an up-and-down movement and are complex in structure. Therefore, the direction and amount of thermal expansion and contraction vary from element to element and that makes it difficult to include each thermal behavior of the components in the design. DGs used in standby power application, including nuclear power plants need to start and assume loads in a short time. The interaction and combined effects of these components negatively impact the ability of the engine to start. In order to meet the start and load time requirements a DG must be kept warm, typically 35°C. It is important that DGs maintain the engine coolant and lube-oil at adequate temperature by the use of keep warm systems. This optimizes conditions in terms of starting reliability and reduces stress on the mechanical portion of the engine during emergency starts. Additionally, keep warm systems prevent damage and improper operation of components caused by friction, due to the rapid thermal expansion and contraction of components, which occur at startup. Each manufacturer has their own recommended temperature for warm standby conditions that are based on the dynamic characteristics, starting characteristics, and ignition characteristics of the manufacturer's DG design.

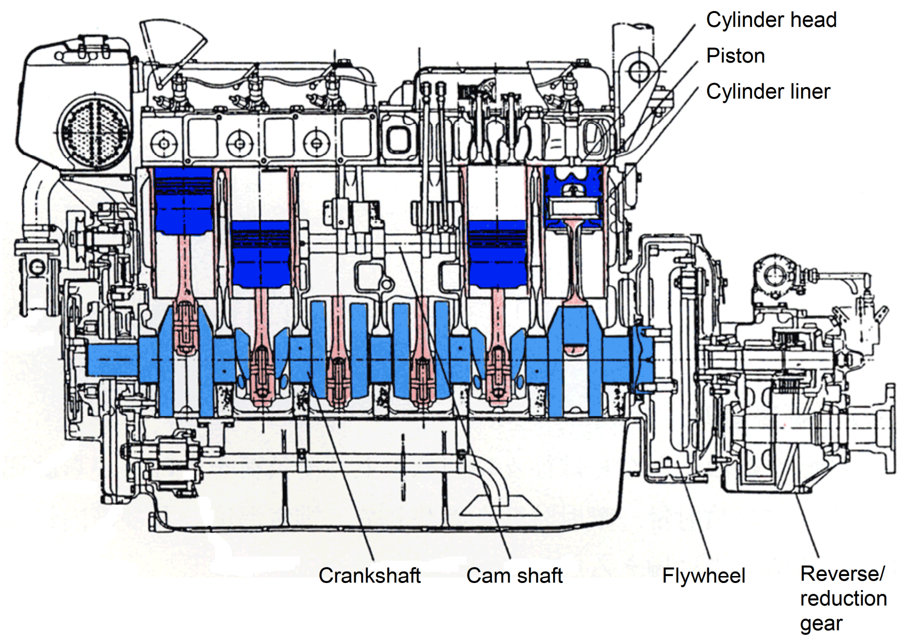

Figure E.1.1-1 Diesel Engine Structure

E.1.2 GAS TURBINE GENERATOR (GTG)

GTGs are different from DGs in structure, characteristics/starting characteristics, and ignition characteristics. As indicated by Figure E.1.2-1, unlike DGs, GTGs produce a rotary motion directly, not a reciprocating motion that is converted to a rotary motion. GTGs start by rotating a rotor/blade disks, mechanically, with external power and igniting fuel when the gas turbine reaches a specified speed that is typically around 20% of the operating speed. The number of critical components necessary to establish combustion is dramatically reduced from those of a DG.

Additionally, since the thermal expansion and contraction is only toward the circumferential and axial direction and the components are few, it is easy to include the thermal behavior of the critical components in the design. The negative effects of thermal expansion and the interaction of the critical components and material are well known and have been eliminated or significantly reduced in the design. This significantly reduces the effect of starting temperature conditions that impact starting the unit. Therefore, the start reliability is significantly higher across a broader range of starting conditions.

In conclusion, unlike DGs, whose starting characteristics are affected by heat expansion and contraction of components, it is not necessary for ground-based GTGs to be kept warm and the design of many GTGs does not require that they be kept in a warm condition. This enables the GTG to consistently start under a broad range of ambient and component temperatures. None of the inherent operating principles are significantly affected by ambient or component temperatures at the time of starting.

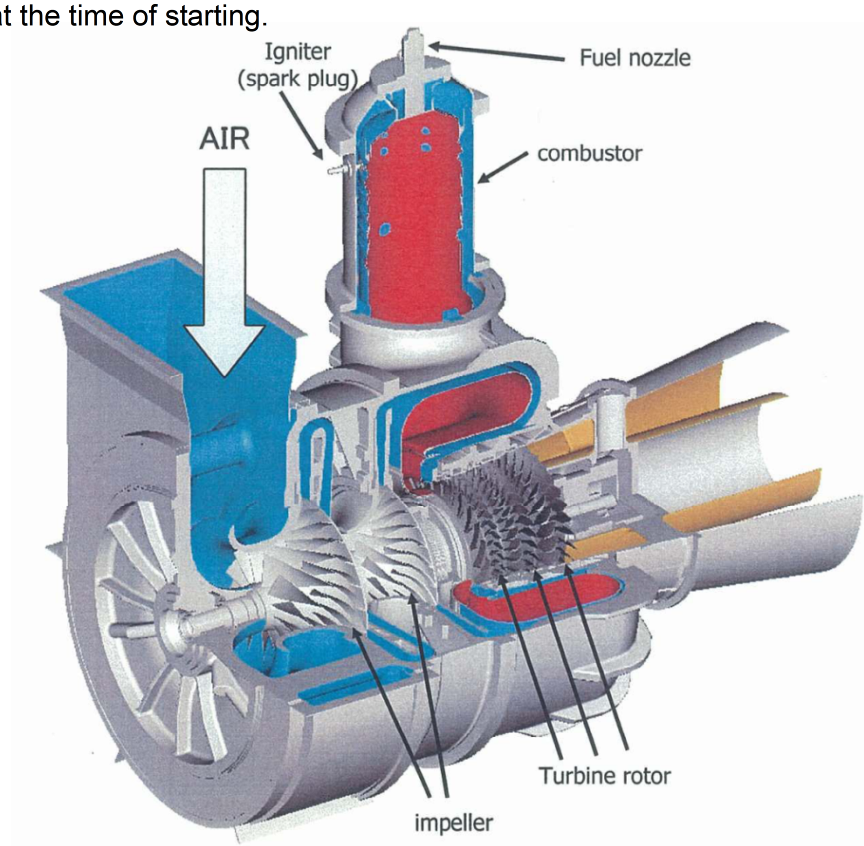

Figure E.1.2-1 Gas Turbine Engine Structure

E.2.0 Starting Functional Comparison

Impact evaluation of cold/hot start (starting reliability) is shown in Table E.2.0-1.

Table E.2.0-1 Impact Evaluation of Cold/Hot Start (Starting Reliability)

Starting Basic Function	Major Component or subsystem	Function	Temperature effects		Diesel Engine Differences
			Hot Start (Normal Operating)	Cold Start (Warm Standby)	
Ignition	Combustion Chamber	To contain the combustion and convert the energy released to mechanical energy; rotational torque and velocity. The combustion chamber is also where the air and fuel are mixed and combust to produce energy.	**Independent of Temperature**	**Independent of Temperature**	Diesel engines are significantly more sensitive to low ambient temperature conditions. A diesel engine relies upon the heat of compression to initiate combustion. The flow of air into the cylinders is directly related to the movement of the pistons during starting.
			Basis Discussion: At ignition any air remaining in the combustion chamber from the previous operating cycle is effectively purged during the starting sequence as the main shaft is accelerated. Therefore, there is no difference in the air temperature within the combustion chamber during starting. However, there is a difference in the fuel oil temperature which may affect ignition performance. At a low temperature, the fuel viscosity is high. Although it has no impact on ignition performance within the specified range of viscosity by the manufacturer (see fuel properties discussion below), at a low temperature outside the range, ignition performance may be impacted. An area electric heater is provided to maintain the fuel oil in required condition as necessary.		

<table>
<tr><th rowspan="2">Starting Basic Function</th><th rowspan="2">Major Component or subsystem</th><th rowspan="2">Function</th><th colspan="2">Temperature effects</th><th rowspan="2">Diesel Engine Differences</th></tr>
<tr><th>Hot Start (Normal Operating)</th><th>Cold Start (Warm Standby)</th></tr>
<tr><td rowspan="4">Ignition</td><td rowspan="2">Igniter</td><td rowspan="2">The function of the igniter is to initiate combustion of the fuel during starting. An igniter is similar to a spark plug in an internal combustion engine utilizing rapidly burning fuels such as gasoline.</td><td>Independent of temperature. The spark produced contains sufficient energy to initiate combustion of the fuel independent of the temperature of the fuel air mixture.</td><td>-Independent of Temperature</td><td rowspan="2">Typical Diesel engines do not contain igniters or spark plugs within the cylinders. They rely only upon the heat of compression to ignite the fuel air mixture. Consequently are susceptible cold temperatures.</td></tr>
<tr><td colspan="2"><u>Basis Discussion:</u> The presence of an igniter in the combustion chamber is to initiate the combustion of the fuel. The operation of an igniter produces a highly localized area of very high temperature that will initiate combustion independent of temperature.</td></tr>
<tr><td rowspan="2">Fuel properties</td><td rowspan="2">Variations of Fuel temperature affect the energy content or the amount of fuel delivered to the combustion chamber (s).</td><td>Negligible; Fuel density is less at higher temperatures.</td><td>Negligible; Fuel viscosity and density is greater.</td><td rowspan="2"></td></tr>
<tr><td colspan="2"><u>Basis Discussion:</u> Neither condition significantly affects the ability to start and assume load. The turbine is designed to use standard fuels. The effects will be insignificant provided that the fuel is within specified properties set by the manufacturer.</td></tr>
</table>

Starting Basic Function	Major Component or subsystem	Function	Temperature effects		Diesel Engine Differences
			Hot Start (Normal Operating)	Cold Start (Warm Standby)	
	Rotation	The function of the starter motors is to bring the turbine to its starting rotational speed, typically approximately 20% of Rated.	**Negligible**; under high ambient or operating temperatures friction is less due to oil viscosity, the turbine may reach starting speed slightly quicker.	**Negligible;** under warm standby temperatures or low ambient temperatures friction is greater due to oil viscosity; the turbine may take slightly longer to reach starting speed.	Temperatures less the 50°C significantly reduces the start reliability of Diesel engines. As a compensatory action "keep warm systems," are generally required for Diesel engines utilized in standby power applications.
			Basis Discussion: Combustion chamber compression is established by the rotation of the main shaft; it does not depend upon seals or piston rings as in an engine driven generator. Because it does not rely upon components that are sensitive to tolerances which are impacted by temperature performance is not impacted.		
Fuel control	Fuel pump	The function of the fuel pump is to deliver fuel at the correct pressure and rate to the combustion chamber through a set of control and stop valves.	**Independent of temperature.**	**Independent of temperature.**	With a diesel engine the amount of fuel injected into the cylinders is controlled by the engine governor in conjunction with the fuel injectors.
			Basis Discussion: A separate DC motor driven starting fuel pump is provided to supply fuel during starting. The flow rate required during starting is less than 25% of rated load. The fuel oil pump is insulated from the high temperature turbine components; therefore independent of turbine temperature. The engine mounted fuel pump is designed to deliver the required flow rate for rated load conditions plus margin during normal operations.		
	Fuel stop valve /Fuel control valve	The function of the fuel control valves and piping are to control the amount of fuel delivered to the combustion chamber and is proportional to the load.	**- Independent of temperature**	**- Independent of temperature**	Diesel engines do not have fuel control valves, the amount of fuel injected into the cylinder is controlled by the fuel injectors and engine governor.
			Basis Discussion: The fuel control valves and piping are designed to deliver the required flow rate for rated load conditions plus margin. The flow rate required during starting is less than 25% of rated load. The flow rate is controlled by the engine governor and flow control valves. These valves are insulated from the high temperature turbine components; therefore independent of turbine temperature.		

E.3.0 Manufacturer’s Analysis

Manufacturer’s analysis is shown in Table E.3.0-1.

Table E.3.0-1 Manufacturer's Analysis of Starting Reliability

		Difference in performance between cold/hot starts	Is it cold or hot start that affects performance negatively	Influence on starting reliability
Ignition performance	Fuel nozzle	**Independent of Temperature**	-	**Independent of Temperature**
	Combustor	**Negligible** (Any remaining air is purged.)	-	**Independent of Temperature** (Since large volumes of air are drawn into the combustor at startup, at the time of ignition the ambient temperature is about the same between cold and hot start conditions. In addition, none of our record shows a failure of start caused by the ambient temperature of combustors.)
	Exciter/ igniter	**Independent of Temperature**	-	**Independent of Temperature**
	Fuel property	**Independent of Temperature**	-	**Independent of Temperature**
Rotational resistance characteristics	Lube oil viscosity of GT bearing	**Negligible** (In a cold condition lube oil viscosity is higher and rotational resistance increases.)	Cold	**Independent of Temperature** (It takes longer (about 1 second) to start in a cold starting condition because rotational resistance increases due to an increase in the lube oil viscosity. However, lube oil viscosity has no influence on starting reliability.)
	Labyrinth seal clearance/ blade tip clearance	**Negligible** (The clearance decreases at a high temperature.)	Hot	**Independent of Temperature** (The clearance is designed assuming an increase during operation. The temperature is higher and the labyrinth seal clearance/ blade tip clearance are smaller during operation than startup. Therefore, the starting reliability is not affected by the temperature at startup and none of our record shows a failure of start caused by rubbing due to a higher temperature.)
Starting torque characteristics	Starter	**Independent of Temperature**	-	**Independent of Temperature**

		Difference in performance between cold/hot starts	Is it cold or hot start that affects performance negatively	Influence on starting reliability
Fuel control performance	Fuel pump	**Independent of Temperature**	-	**Independent of Temperature**
	Fuel stop valve	**Independent of Temperature**	-	**Independent of Temperature**
	Fuel control valve	**Independent of Temperature**	-	**Independent of Temperature** (The fuel amount is automatically controlled depending on the exhaust gas temperature of startup. When the temperature of the engine is either high or low, the fuel amount is suitably controlled and there is no influence on the starting reliability including starting time.)

Appendix F Reliability

F.1.0 US EDG Reliability Data

(1) NUREG/CR-6928 reports the reliability of nuclear EDGs. This data is based on the EPIX database which collects and evaluates operational experiences of nuclear EDG units applied to US NPPs. In addition, the NRC issued a report in 2007 about the reliability of EDGs based on the EPIX database. (Note 1)
Both NUREG/CR-6928 and the NRC's 2007 report are based on the EPIX database. However, the NRC's 2007 report considered longer period of operation experiences than periods evaluated in NUREG/CR-6928.
(Note 1) "Enhanced Component Performance Study Emergency Diesel Generators 1998-2007"

(2) The NRC's 2007 report shows that 223 units consist of a large variety of products of engine. The report provides the breakdown of 223 units shown in Table F.1.1-1 and Table F.1.1-2. This shows that the design of EDGs (manufacturer, type, output, number of cylinders) exhibit significant design variations.

Table F.1.1-1 US EDG Data

Output	Number of Units
50 to 249 kW	2
1000 to 4999 kW	169
Over 5000 kW	52

Table F.1.1-2 US EDG Data (continued)

Manufacturer	Number of Units
A	4
B	3
C	8
D	20
E	24
F	65
G	31
H	68

(3) Even if it is assumed that one manufacturer supplied only one type of EDG, the number of identical EDGs is estimated to be only 68 units, maximum. If one manufacturer had supplied two or more EDGs having the same type of engines, it is estimated that the largest identical engine group does not consist of more than 30 units. Also this data is classified from only difference of engine type. If the classification included the differences of support system components (cooling, starting, and lubrication) are considered, the number of identical GTG sets is less.

(4) US reliability data is evaluated based upon operational experiences of those various products, in NUREG/CR-6928. And “Failure to Start (FTS)” is calculated as follows:.

- mean: 4.53×10^{-3} / demand
- 95%: 1.32×10^{-2} / demand

F.2.0 Reliability Data of Japanese Commercial Emergency GTGs of the Same Series and Manufacturer as the US-APWR GTG, Used for Non-nuclear Applications

(1) MHI has shown the NRC the operational experiences of Japanese commercial emergency GTGs of the same series and manufacturer as the US-APWR GTG, used for non-nuclear applications in MHI RAI response No.5 issued on June 6 in 2008 shown in Table F.2.0-1.

Table F.2.0-1 Reliability Data of Japanese Commercial Emergency GTGs of the Same Series and Manufacturer as the US-APWR GTG, Used for Non-nuclear Applications

Data Group No.	Number of GTG Sets	Number of Failures/ Number of Starts	Type			
			Output (kVA)	Single engine or Twin engine	Fuel Type	Starting system
1	70	2/4891	150 to 300	Single	Diesel Oil	DC motor
2	19	0/2503	1000 to 1750	Single	Kerosene	DC motor
3	9		1000 to 1750	Single	Diesel Oil	DC motor
4	157		1000 to 1750	Single	Heavy Oil	DC motor
5	1		1000 to 1750	Single	Kerosene	Air
6	9		1000 to 1750	Single	Heavy Oil	Air
7	10		2000 to 4500	Twin	Kerosene	DC motor
8	5		2000 to 4500	Twin	Diesel Oil	DC motor
9	90		2000 to 4500	Twin	Heavy Oil	DC motor
10	5		2000 to 4500	Twin	Heavy Oil	Air

(2) The GPS series is designed based on same design concept and manufacturing control. The data of GPS series is applicable to evaluate the EPS's reliability using the same approach as NUREG's.

(note)
MHI shows the classical estimation as follows;

- mean: 2.7×10^{-4} / demand (2/7394)
- S (standard deviation): 1.91×10^{-4} / demand
  S = {p(1-p)/n}1/2
- maximum (95% distribution):
  mean + 2S = 6.52×10^{-4} / demand

Mean and 95% maximum are low than US nuclear GTG's data.

(3) MHI understands there are differences between GTG's data, which is based on commercial products, and EDG's data, which is based on nuclear GTG's data qualified as safety-related. It is proper to consider that product qualified as nuclear safety-related would have higher reliability than commercial product. However, MHI has never used Kawasaki engines for nuclear safety-related application. MHI performs detailed analysis of the data of commercial products to be able to evaluate reliability precisely.

F.3.0 MHI's Reliability Verification

(1) As explained before by MHI, the reliability target of US-APWR Class 1E GTG is as shown below. It is based on US EDG's data of NUREG-CR/6928. And this value is used to perform PRA analysis.

Fail to Start
- Mean : 5.0×10^{-3} / demand
- 95% maximum : 1.5×10^{-2} / demand

Fail to Run
- Mean : 8.0×10^{-4} / hr
- 95% maximum : 2.0×10^{-3} / hr

(2) MHI shows GTS6000 satisfies with reliability target of US-APWR using Bayesian approach.
(note)
Bayesian approach is one of general method of statistics, and is widely used to evaluate component reliability.
NUREG-CR/6928 also uses this approach.

(3) In order to estimate GTS6000's reliability accurately, collection of data based on appropriate categorization is necessary. MHI has analyzed the GPS's operational data. Operational data has been collected from manufacturer's records as shown in Tables F.3.0-1 and F.3.0-2.

Table F.3.0-1 GPS's Operational Data

Product	Output(kVA)	Single engine or Twin engine	Fuel Type	Starting system	Failure/Number of starts	Failure/Operation hours
1	2000	Twin	Heavy Oil	Air	0 /251 d	0 /98 hr
2	2000	Twin	Heavy Oil	DC	0 /265 d	0 /75.4 hr
3	2000	Twin	Diesel Oil	DC	0 /100 d	0 /71.3 hr
4	2000	Twin	Kerosene	DC	0 /1053 d	0 /205 hr
5	2500	Twin	Heavy Oil	Air	0 /383 d	0 /1129.8 hr
6	2500	Twin	Heavy Oil	DC	0 /95 d	0 /16.4 hr
7	4000	Twin	Heavy Oil	Air	0 /540 d	0 /982 hr
8	4000	Twin	Heavy Oil	DC	0 /149 d	0 /96.8 hr
9	4000	Twin	Diesel Oil	Air	0 /225 d	0 /156.4 hr
10	4000	Twin	Diesel Oil	DC	0 /105 d	0 /50.8 hr
11	4000	Twin	Kerosene	DC	0 /263 d	0 /109.6 hr

Table F.3.0-2 GPS's Operational Data (continued)

Product	Output(kVA)	Single engine or Twin engine	Fuel Type	Starting system	Failure/Number of starts	Failure/Operation hours
12	4500	Twin	Heavy Oil	Air	0 /327 d	0 /125.1 hr
13	4500	Twin	Heavy Oil	DC	0 /130 d	0 /63.2 hr
14	4500	Twin	Diesel Oil	DC	0 /69 d	0 /80.3 hr
15	4500	Twin	Diesel Oil	DC	0 /147 d	0 /32.1 hr
16	4500	Twin	Kerosene	Air	0 /341 d	0 /455.1 hr
17	4500	Twin	Kerosene	DC	0 /251 d	0 /68.0 hr
18	5000	Twin	Unidentified	DC	0 /48 d	Operation period of those products are short. These are not used for evaluation as conservative.
19	5000	Twin	Unidentified	DC	0 /48 d	
20	6000	Twin	Unidentified	DC	0 /24 d	
21	6000	Twin	Unidentified	DC	0 /24 d	
22	6000	Twin	Unidentified	DC	0 /13 d	
23	6000	Twin	Unidentified	DC	0 /13 d	
24	6000	Twin	Unidentified	DC	0 /12 d	
25	6000	Twin	Unidentified	DC	0 /12 d	
26	6000	Twin	Unidentified	DC	0 /6 d	
27	6000	Twin	Unidentified	DC	0 /1 d	

(4) Data collection of GTG fail to start

- GPS series have been produced with common design concept such as structure, dynamic characteristics and materials. Increase of output is achieved by sizing up the design of small output product analogously. The smaller the difference of output is, the more similar design the products have. MHI applies GPS6000 as EPS. GPS5000 is similar design as GPS6000. Also, GPS4000/4500 are nearly the same design as GPS6000, and there are no significant difference of starting capability based on operation experiences. Another mean of increasing of output is using two engines with one generator. Over GPS 2000 products are all twin type.

- Starting type is also considered whether air or DC motor.

- MHI has selected the data of Table F.3.0-3 as follows;
  - Data of GPS4000 to 6000 with air starting type
    → 1433 demands with 0 failure

  This data is used to perform Bayesian approach of GTG reliability.

(5) Data collection of GTG fail to run

From view point of running reliability, type of starting system is not needed to consider. Also, there are no significant differences from operation experiences of large output twin engine products of over GPS2000. MHI has classified the data of running time into over GPS2000 and over GPS4000.

1) Data of over GPS2000 → 3820 hours with 0 failure
2) Data of over GPS4000 → 2224 hours with 0 failure

Although MHI evaluates it is appropriate to use both 1) and 2) above to perform Bayesian approach, MHI performs evaluation using only data of 2) conservatively.

(6) Reliability estimation of US-APWR GTGs based on reliability data of Japanese commercial emergency GTGs of the same series and manufacturer as the US-APWR GTG, used for non-nuclear applications

- Applicable data
  - 1433 demands with 0 failure
  - 2224 run hours with 0 failure

- Uncertainty of failure rate/probability
  - Estimated applying simplified constrained non-informative distribution

Table F.3.0-3 Reliability Estimation of US-APWR GTGs Based on Reliability Data of Japanese Commercial Emergency GTGs of the Same Series and Manufacturer as the US-APWR GTG, Used for Non-nuclear Applications

	5%	Mean	95%	Distribution		
				Type	a	b
Fail to start	1.4E-6	3.5E-4	1.3E-3	Beta	0.5	1433
Fail to run	8.9E-7	2.2E-4	8.3E-4	Gamma	0.5	2224

(7) Reliability Comparison between EDG and GTG
NUREG/CR-6928 defines the EDG system boundary to include the diesel engine with all components in the exhaust path, electrical generator, generator exciter, output breaker, combustion air, lube oil systems, fuel oil system, starting compressed air system, and local instrumentation and control circuitry. Per Figure 4.0-1 of this report all of the support systems listed in NUREG/CR-6928 were included in the initial type testing with the exception of the output circuit breaker. Consequently, the estimated failure rate includes the GTG and its supporting system failure rates with the exception of the output circuit breaker. The output circuit breaker is in series with the GTG; therefore, the open/close failure rate and the spurious operation failure rate for the output circuit breaker are added to the estimated failure rate for the GTG. The comparison is shown in Tables F.3.0-4 and F.3.0-5.

Table F.3.0-4 Start Reliability

NUREG/CR-6928 EDG	Failure rate (/ demand)	US-APWR GTG	Failure rate (/ demand)
Class 1E Medium Voltage Bus EDG breaker EDG	5.0×10^{-3} (Fail to start)	Class 1E Medium Voltage Bus GTG breaker GTG	GTG breaker: 2.55×10^{-3} (Fail to open/close; NUREG/CR-6928) GTG: 3.5×10^{-4} (Fail to start; MHI estimated)
Total	5.0×10^{-3}	Total	2.9×10^{-3}

Table F.3.0-5 Run Reliability

NUREG/CR-6928 EDG	Failure rate (/ hr)	US-APWR GTG	Failure rate (/ hr)
Class 1E Medium Voltage Bus EDG breaker EDG	8.0×10^{-4} (Fail to run)	Class 1E Medium Voltage Bus GTG breaker GTG	GTG breaker: 1.71×10^{-7} (Spurious operation; NUREG6928) GTG: 2.2×10^{-4} (Fail to run; MHI estimated)
Total	8.0×10^{-4}	Total	2.20171×10^{-4}

F.4.0 Requirement for Initial Type Test

(1) According to a domestic GTG's field data, the GTG failure rate is statistically evaluated as 3.5×10^{-4}/demand, which proves high reliability of the GTG.

(2) R.G.1.155 describes the requirement for reliability of Class 1E EDG: 0.975 with 95% confidence or 0.95 with 95% confidence. MHI has chosen 0.975 with 95% confidence as a reliability target.

(3) The initial type test condition to achieve reliability 0.975 with 95% confidence is statistically evaluated with the following math formula:
Reference; Probability Concepts in Engineering Planning and Design
Alfredo H-S. Ang Wilson H.Tang

$$\sum_{i=0}^{r} \frac{n!}{(n-i)!\,i!}(1-R)^{i} \cdot R^{(n-i)} = 1-C$$

n: number of trials
c: confidence
R: reliability
r: number of failure

(4) If the number of failure (r) is 0, the above formula is rearranged as follows:

$$R^n = 1-C$$

If the number of trials 150 is assigned to the above, 97.75% of confidence is obtained as follows:

$$0.975^n = 1-C$$
$$C = 1-(0.975^{150})$$
$$=97.75\%$$

As a conclusion, if the GTG startup test results in 150 trials with zero failures, that means the reliability of GTGs is higher than 0.975 with approximately 98% confidence.
In this way, the initial type test condition to achieve the required reliability has been determined to be 150 times with no failure.

Appendix G Initial Type Test

Figure G.1.0-1 Voltage Dip with Motor Starting

Appendix H Result of Seismic Test for Gas Turbine Engine and Gearbox Assembly

Table H.1.0-1 List of the Test Run

Figure H.1.0-1 Vertical Resonance Search for Test Run 1 (Sheet 1 of 9)

Figure H.1.0-1 Vertical Resonance Search for Test Run 1 (Sheet 2 of 9)

Figure H.1.0-1 Vertical Resonance Search for Test Run 1 (Sheet 3 of 9)

Figure H.1.0-1 Vertical Resonance Search for Test Run 1 (Sheet 4 of 9)

Figure H.1.0-1 Vertical Resonance Search for Test Run 1 (Sheet 5 of 9)

Figure H.1.0-1 Vertical Resonance Search for Test Run 1 (Sheet 6 of 9)

Figure H.1.0-1 Vertical Resonance Search for Test Run 1 (Sheet 7 of 9)

Figure H.1.0-1 Vertical Resonance Search for Test Run 1 (Sheet 8 of 9)

Figure H.1.0-1 Vertical Resonance Search for Test Run 1 (Sheet 9 of 9)

Figure H.1.0-2 Horizontal Resonance Search for Test Run 2 (Sheet 1 of 9)

Figure H.1.0-2 Horizontal Resonance Search for Test Run 2 (Sheet 2 of 9)

Figure H.1.0-2 Horizontal Resonance Search for Test Run 2 (Sheet 3 of 9)

Figure H.1.0-2 Horizontal Resonance Search for Test Run 2 (Sheet 4 of 9)

Figure H.1.0-2 Horizontal Resonance Search for Test Run 2 (Sheet 5 of 9)

Figure H.1.0-2 Horizontal Resonance Search for Test Run 2 (Sheet 6 of 9)

Figure H.1.0-2 Horizontal Resonance Search for Test Run 2 (Sheet 7 of 9)

Figure H.1.0-2 Horizontal Resonance Search for Test Run 2 (Sheet 8 of 9)

Figure H.1.0-2 Horizontal Resonance Search for Test Run 2 (Sheet 9 of 9)

Figure H.1.0-3 Random Multifrequency Test for Test Run 3 (Sheet 1 of 2)

Figure H.1.0-3 Random Multifrequency Test for Test Run 3 (Sheet 2 of 2)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 1 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 2 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 3 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 4 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 5 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 6 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 7 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 8 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 9 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 10 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 11 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 12 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 13 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 14 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 15 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 16 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 17 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 18 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 19 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 20 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 21 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 22 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 23 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 24 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 25 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 26 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 27 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 28 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 29 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 30 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 31 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 32 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 33 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 34 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 35 of 40)

Figure H.1.0-4 Random Multifrequency Test for Test Run 4 (Sheet 36 of 40)

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Appendix I Result of Seismic Test for Generator Bearing Lubrication Oil System

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Table I.1.0-1 North-South RRS for Generator Bearing Lubrication Oil System (Sheet 2 of 2)

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Table I.1.0-2 East-West RRS for Generator Bearing Lubrication Oil System
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Table I.1.0-3 Vertical RRS for Generator Bearing Lubrication Oil System
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Table I.1.0-3 Vertical RRS for Generator Bearing Lubrication Oil System (Sheet 2 of 2)

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Figure I.1.0-1 OBE 1 Test Response Spectra Plots and Time History Plots (Sheet 2 of 3)

Figure I.1.0-1 OBE 1 Test Response Spectra Plots and Time History Plots (Sheet 3 of 3)

Figure I.1.0-2 OBE 2 Test Response Spectra Plots and Time History Plots (Sheet 1 of 3)

Figure I.1.0-2 OBE 2 Test Response Spectra Plots and Time History Plots (Sheet 2 of 3)

Figure I.1.0-2 OBE 2 Test Response Spectra Plots and Time History Plots (Sheet 3 of 3)

Figure I.1.0-3 OBE 3 Test Response Spectra Plots and Time History Plots (Sheet 1 of 3)

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Figure I.1.0-4 OBE 4 Test Response Spectra Plots and Time History Plots (Sheet 1 of 3)

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Figure I.1.0-7 OBE 1 Correlation Plots

Figure I.1.0-8 OBE 1 Stationarity Plots

Figure I.1.0-9 SSE 1 Correlation Plots

Figure I.1.0-10 SSE 1 Stationarity Plots

Appendix J Result of Seismic Test for Lube Oil Cooler Fan Assembly

Table J.1.0-1 North-South RRS for Lube Oil Cooler Fan Assembly (Sheet 1 of 2)

Table J.1.0-1 North-South RRS for Lube Oil Cooler Fan Assembly (Sheet 2 of 2)

Table J.1.0-2 East-West RRS for Lube Oil Cooler Fan Assembly (Sheet 1 of 2)

Table J.1.0-2 East-West RRS for Lube Oil Cooler Fan Assembly (Sheet 2 of 2)

Table J.1.0-3 Vertical RRS for Lube Oil Cooler Fan Assembly (Sheet 1 of 2)

Table J.1.0-3 Vertical RRS for Lube Oil Cooler Fan Assembly (Sheet 2 of 2)

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Figure J.1.0-1 OBE 1 Test Response Spectra Plots and Time History Plots (Sheet 2 of 3)

Figure J.1.0-1 OBE 1 Test Response Spectra Plots and Time History Plots (Sheet 3 of 3)

Figure J.1.0-2 OBE 2 Test Response Spectra Plots and Time History Plots (Sheet 1 of 3)

Figure J.1.0-2 OBE 2 Test Response Spectra Plots and Time History Plots (Sheet 2 of 3)

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Figure J.1.0-3 OBE 3 Test Response Spectra Plots and Time History Plots (Sheet 1 of 3)

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Figure J.1.0-3 OBE 3 Test Response Spectra Plots and Time History Plots (Sheet 3 of 3)

Figure J.1.0-4 OBE 4 Test Response Spectra Plots and Time History Plots (Sheet 1 of 3)

Figure J.1.0-4 OBE 4 Test Response Spectra Plots and Time History Plots (Sheet 2 of 3)

Figure J.1.0-4 OBE 4 Test Response Spectra Plots and Time History Plots (Sheet 3 of 3)

Figure J.1.0-5 OBE 5 Test Response Spectra Plots and Time History Plots (Sheet 1 of 3)

Figure J.1.0-5 OBE 5 Test Response Spectra Plots and Time History Plots (Sheet 2 of 3)

Figure J.1.0-5 OBE 5 Test Response Spectra Plots and Time History Plots (Sheet 3 of 3)

Figure J.1.0-6 SSE 1 Test Response Spectra Plots and Time History Plots (Sheet 1 of 3)

Figure J.1.0-6 SSE 1 Test Response Spectra Plots and Time History Plots (Sheet 2 of 3)

Figure J.1.0-6 SSE 1 Test Response Spectra Plots and Time History Plots (Sheet 3 of 3)

Figure J.1.0-7 OBE 1 Correlation Plots

Figure J.1.0-8 OBE 1 Stationarity Plots

Figure J.1.0-9 SSE 1 Correlation Plots

Figure J.1.0-10 SSE 1 Stationarity Plots

Appendix K Fuel Nozzle Maintenance

K.1.0 Basis of 50 Start Maintenance Interval

This maintenance activity is one of several recommended by the engine manufacturer, Kawasaki Heavy Industries (KHI). The intent is to prevent the buildup of gums and other insoluble materials, including carbon within the nozzle and the nozzle tip. This is commonly referred to as fuel nozzle “coking.” The effect of severe coking is a reduction in ignition and running performance. The engine manufacturer recommends the fuel nozzle maintenance (cleaning) for all users, and routinely performs cleaning as part of its preventive maintenance program. According to the engine manufacturer, cleaning the fuel nozzle every 50 starts is conservative, based on the engine manufacturer's field experience for GTGs of its type.

The impact of not cleaning the fuel nozzles, as with any preventive maintenance activity, will affect performance over time. In the case of gas turbine engines, not cleaning the fuel nozzles will ultimately lead to a buildup of gums and other insoluble materials, including carbon that will delay the GTG start time and load capability. Although the engine manufacturer recommends fuel nozzle cleaning after every 50 engine starts based on their typical industrial experience, this cleaning activity cannot be defined as essential to the successful completion of the 150 start and load acceptance tests for the US-APWR application. This is because the quality of fuel for nuclear applications, such as the US-APWR, is better than the quality of other typical industrial applications which is the engine manufacturer's basis for their maintenance procedure. However, because fuel nozzle cleaning is the engine manufacturer’s recommended maintenance item required during the series of tests; it was included in the test sequence. The engine manufacturer strongly recommends fuel nozzle cleaning after every 50 engine starts.

K.2.0 “As found” Fuel Nozzle Condition

During each fuel nozzle cleaning, there was some slight surface discoloration found on the portions of the nozzles that were exposed to the high temperatures within the combustion chamber. Port or fuel passageway clogging was not evident or observed. The surface discoloration is the result of gum like deposits from the fuel that plated out on the fuel nozzle as the fuel vaporized while in contact with the nozzle or condensed on the cooler parts of the nozzle during starting. The discoloration was not excessive and was typical of that observed for the quality of the fuel being used. The quality of the fuel oil used in a nuclear power plant is better than in other industrial applications and that used during the testing. Fuel quality is usually No. 2 diesel fuel, or better.

K.3.0 An Expression of the Engine Manufacturer's View on Fuel Nozzle Maintenance

K.4.0 Fuel Nozzle Cleaning Procedure

Manufacturer's maintenance procedure approved by MHI is shown in Table K.4.0-1.

Table K.4.0-1 Work Instruction Sheet (Sheet 1 of 2)

Table K.4.0-1 Work Instruction Sheet (Sheet 2 of 2)

Appendix L Load Bank Failure

L.1.0 Description of the Event

During Start and Load Acceptance Test Number 128, the load bank failed. This resulted in a sudden unplanned reactive load addition on the GTG. The load bank failure occurred approximately 15 minutes into Test No. 128, after the GTG had successfully started and accepted the test load; however, before the machine temperature stabilized within 10ºF of normal operating temperature. Consequently, the third acceptance criterion was not achieved and test 128 was classified as “Disregarded” per IEEE Std 387-1995 Section 6.2.2.e).5).

The load bank failure caused an approximately 200- 300% overload of the GTG, which tripped on “under frequency”. The GTG responded to the load bank failure as expected and in accordance with the protection scheme established for the test.

After the under-frequency shutdown of the GTG, the Qualification Vendor investigated the load bank facility. It was discovered that a major electrical fault had occurred in one of the reactive load banks. The load bank facility includes individual cabinets, each containing 375 KVAR inductive loads. The actual load available at the time of the GTG testing was 4,729 KVAR. One of the load banks had significant burn marks, sheet metal burnout, and loss of 3-phase bus work. A large sheet metal cover was found 8-10 feet away from the unit, having been explosively burned and dislodged from its normal position.

Subsequent to a visual inspection by the Qualification Vendor, MHI, and the GT engine manufacturer’s representatives, the machine was barred over (purged) three times and then started. The GTG successfully started, accepted load and reached stable operating temperatures. The parameters were closely monitored and were determined to be within normal expected values. Therefore, the Start and Load Acceptance testing was allowed to continue.

Start and Load Acceptance testing was resumed by repeating Test No. 128. The GTG successfully started and accepted load. During the load run, a whistling noise that had not been present during previous test runs was noticed coming from the enclosure that had not been present during previous test runs. The GTG parameters were stable and within normal values, therefore Test No. 128 was allowed to continue to completion. During the subsequent investigation into the source of the noise, deformation of the combustion air duct was noticed. During further investigation and removal of the deformed duct, it was discovered that the Foreign Object Debris (FOD) screen had been damaged and a sound insulation component was found inside the intake air plenum. The component had been displaced from its location in the ceiling of the GTG enclosure.

According to the engine manufacturer’s technical representative, the overload from the load bank failure had created a pressure pulse within the intake air ducting that dislodged the sound insulating component. In addition to the displaced component, two other similar components were found loose but not displaced. The component that was dislodged from the ceiling consisted of an outer steel welded box, insulating material, and a perforated cover that was riveted to the box. The enclosure manufacturer failed to appropriately weld the assembly in place. During the load bank failure, the assembly became displaced from its location and fell through the FOD screen, lodging in the GT engine intake air plenum. The failure to weld these sound insulating components into the enclosure frame was classified as a manufacturing defect.

L.1.1 Probable Cause of the Load Bank Failure

Due to normal load bank maintenance, the Qualification Vendor had, over time, replaced many of the control contactors that were originally supplied with the equipment. The original contactors included rigid copper connectors that provided physical support for the 3-phase control bus. However as the years progressed, the original style contactors became obsolete. The newer contactors were available only with flexible conductors which provide no support to the control bus work. This had the effect of leaving the bus work susceptible to movement when energized. The Qualification Vendor believes the lack of adequate support at the end of the copper bus work allowed two phases to contact each other creating an explosive phase to phase to ground fault. The cause of load bank failure cannot be attributed to the GTG. The GTG was stable and operating well within nominal values for all parameters when the load bank failure occurred.

L.2.0 Potential for Similar Occurrence in Operating Plants

The potential effects fall into two distinct classes; electrical damage to the generator or exciter, and mechanical damage to the turbine engine.

L2.1 Potential for Electrical Damage

With regard to potential electrical damage, the load bank failure is highly similar to a sudden overload (200 to 300%) or a ground fault. In the absence of a second failure within the generator protection scheme the GTG would isolate itself. Within an actual nuclear plant application, the protection scheme is designed to protect the generator from electrical failures to avoid permanent damage to the critical components, (e.g., rotor and stator windings, prime mover, etc.). A methodology of selective fault protection is employed to trip the circuit breaker closest to the fault. In such a situation, the GTG would continue to supply the remaining non faulted safety related loads without interruption. The electrical protection scheme is also designed to isolate the GTG versus tripping the machine. Once the electrical problem is cleared, the GTG could be safely restarted, if necessary, and realigned to supply the loads.

The load characteristics within a plant power distribution system are different from a test load bank. Pure inductive loads rarely exist within a plant. Typical loads are mixed as in a motor for example. A typical squirrel cage induction motor has inductive as well as resistive components, however, they are not distinct and separable. In a test load bank the resisters and inductors are separate and configurable to a range of real and imaginary loads with different lagging power factor. A fault on a typical plant load would be isolated by the protective scheme. A load bank does not have a similar protection scheme. The protection is designed to allow for quick sudden changes in the load characteristics for testing and to protect the test specimen. Although, a sudden load increase many occur within a plant it would not be in the range of 200% of the machine rating. There is no single load that large connected to the safety bus in the US-APWR.

L.2.2 Potential for Mechanical Damage

The manufacturing defect (loose parts in the air flow path) potentially could result in ingesting foreign objects into the turbine engine. The combustion air intake plenum is designed with a 90° turn at the bottom to preclude large and potentially damaging objects from reaching the moving parts. In such an event, the components that were not correctly attached are too large to enter the engine and potentially come into contact with moving parts. Light weight soft fibrous objects such as the sound insulation that may have been pulled into the turbine engine should pass through without damage, as they did in this case.

The most significant potential is the entry of a hard metal object small enough to be entrained in the combustion air, yet large and hard enough to physically damage (chip) the compressor turbine blades. The plenum and ducting are designed with a sufficiently large cross sectional area to keep air velocities below what would be necessary to entrain such objects.

The successful post maintenance run after the load bank failure, the successful Start and Load Acceptance Test No. 128 (repeat) indicated that the enclosure manufacturing defect did not impact the performance of the GTG. During these two test runs and the remaining testing, detectable changes in the performance of the GTG were not observed.

L.3.0 Corrective Action Taken

Load Bank

The Qualification Vendor removed the damaged reactive load bank from service. Excess capacity allowed reconfiguration of the load bank for the remainder of the tests.

Enclosure Manufacturing Defect

The Qualification Vendor reattached the ceiling component back in its original position and temporarily installed clamps to ensure it would remain in place. A design change was not required or made because this was a manufacturing defect, not a design deficiency. The lack of welds which would have prevented the component from being dislodged is clearly a manufacturing defect. The Qualification Vendor discussed this with the manufacturer to ensure it would not be repeated in future units. Additionally, future procurement specifications will clearly require welding of these assemblies to the enclosure frame.

Appendix M Result of Seismic Test for Engine Control Panel

[ ]

[redacted]

Appendix N Result of Seismic Test for ELV Driver

Appendix O Result of Seismic Analysis for Synchronous Generator

Appendix P Result of Seismic Test for Lube Oil Cooler Fan Assembly (DCD Rev.4 Based)

Figure P.1.0-1 OBE 1 Test Response Spectra Plots (Sheet 1 of 2)

Figure P.1.0-1 OBE 1 Test Response Spectra Plots (Sheet 2 of 2)

Table P.1.0-1 OBE 1 Test Response Spectra Tabulated values

Figure P.1.0-2 OBE 1 Correlation with Table-X

Figure P.1.0-3 OBE 1 Correlation with Table-Y

Figure P.1.0-4 OBE 1 Magnitude Squared Coherence with Table-X

Figure P.1.0-5 OBE 1 Magnitude Squared Coherence with Table-Y

Figure P.1.0-6 OBE 1 Power Spectral Density (Sheet 1 of 3)

Figure P.1.0-6 OBE 1 Power Spectral Density (Sheet 2 of 3)

Figure P.1.0-6 OBE 1 Power Spectral Density (Sheet 3 of 3)

Figure P.1.0-7 OBE 2 Test Response Spectra Plots (Sheet 1 of 2)

Figure P.1.0-7 OBE 2 Test Response Spectra Plots (Sheet 2 of 2)

Table P.1.0-2 OBE 2 Test Response Spectra Tabulated values

Figure P.1.0-8 OBE 2 Correlation with Table-X

Figure P.1.0-9 OBE 2 Correlation with Table-Y

Figure P.1.0-10 OBE 2 Magnitude Squared Coherence with Table-X

Figure P.1.0-11 OBE 2 Magnitude Squared Coherence with Table-Y

Figure P.1.0-12 OBE 2 Power Spectral Density (Sheet 1 of 3)

Figure P.1.0-12 OBE 2 Power Spectral Density (Sheet 2 of 3)

Figure P.1.0-12 OBE 2 Power Spectral Density (Sheet 3 of 3)

Figure P.1.0-13 OBE 3 Test Response Spectra Plots (Sheet 1 of 2)

Figure P.1.0-13 OBE 3 Test Response Spectra Plots (Sheet 2 of 2)

Table P.1.0-3 OBE 3 Test Response Spectra Tabulated values

Figure P.1.0-14 OBE 3 Correlation with Table-X

Figure P.1.0-15 OBE 3 Correlation with Table-Y

Figure P.1.0-16 OBE 3 Magnitude Squared Coherence with Table-X

Figure P.1.0-17 OBE 3 Magnitude Squared Coherence with Table-Y

Figure P.1.0-18 OBE 3 Power Spectral Density (Sheet 1 of 3)

Figure P.1.0-18 OBE 3 Power Spectral Density (Sheet 2 of 3)

Figure P.1.0-18 OBE 3 Power Spectral Density (Sheet 3 of 3)

Figure P.1.0-19 OBE 4 Test Response Spectra Plots (Sheet 1 of 2)

Figure P.1.0-19 OBE 4 Test Response Spectra Plots (Sheet 2 of 2)

Table P.1.0-4 OBE 4 Test Response Spectra Tabulated values

Figure P.1.0-20 OBE 4 Correlation with Table-X

Figure P.1.0-21 OBE 4 Correlation with Table-Y

Figure P.1.0-22 OBE 4 Magnitude Squared Coherence with Table-X

Figure P.1.0-23 OBE 4 Magnitude Squared Coherence with Table-Y

Figure P.1.0-24 OBE 4 Power Spectral Density (Sheet 1 of 3)

Figure P.1.0-24 OBE 4 Power Spectral Density (Sheet 2 of 3)

Figure P.1.0-24 OBE 4 Power Spectral Density (Sheet 3 of 3)

Figure P.1.0-25 OBE 5 Test Response Spectra Plots (Sheet 1 of 2)

Figure P.1.0-25 OBE 5 Test Response Spectra Plots (Sheet 2 of 2)

Table P.1.0-5 OBE 5 Test Response Spectra Tabulated values

Figure P.1.0-26 OBE 5 Correlation with Table-X

Figure P.1.0-27 OBE 5 Correlation with Table-Y

Figure P.1.0-28 OBE 5 Magnitude Squared Coherence with Table-X

Figure P.1.0-29 OBE 5 Magnitude Squared Coherence with Table-Y

Figure P.1.0-30 OBE 5 Power Spectral Density (Sheet 1 of 3)

Figure P.1.0-30 OBE 5 Power Spectral Density (Sheet 2 of 3)

Figure P.1.0-30 OBE 5 Power Spectral Density (Sheet 3 of 3)

Figure P.1.0-31 SSE 1 Test Response Spectra Plots (Sheet 1 of 2)

Figure P.1.0-31 SSE 1 Test Response Spectra Plots (Sheet 2 of 2)

Table P.1.0-6 SSE 1 Test Response Spectra Tabulated values

Figure P.1.0-32 SSE 1 Correlation with Table-X

Figure P.1.0-33 SSE 1 Correlation with Table-Y

Figure P.1.0-34 SSE 1 Magnitude Squared Coherence with Table-X

Figure P.1.0-35 SSE 1 Magnitude Squared Coherence with Table-Y

Figure P.1.0-36 SSE 1 Power Spectral Density (Sheet 1 of 3)

Figure P.1.0-36 SSE 1 Power Spectral Density (Sheet 2 of 3)

Figure P.1.0-36 SSE 1 Power Spectral Density (Sheet 3 of 3)