Interim Status Report
Independent Root Cause Analysis Assessment
of the Detroit Edison
Fermi 2 Turbine - Generator Event
on December 25, 1993

July 26, 1994

Prepared by:

Jeffrey S. Summy

Principal Investigators:
Mr. Donnell Kidder
Mr. Ralph Ortolano
Dr. M.S. Mostafa

Reviewed by:

Dr. Chong Chiu

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I Introduction

Mr. Paul Fessler, Technical Services Manager Fermi-2, requested FPI International (FPI) to conduct an independent analysis of the Detroit Edison Root Cause Analysis of the December 25, 1993 Turbine-Generator event. The following interim status report provides the method by which this was conducted along with the conclusions and recommendations from the independent analysis based on available information as of July 15, 1994. This independent analysis was requested to be performed through utilization of data and analysis compiled by the primary root cause analysis team of Detroit Edison personnel lead by Mr. George Trahey. FPI was additionally requested by Mr. Len Fron to provide independent oversight of the root cause failure team activities in the form of process monitoring and team effectiveness.

FPI formulated an overall approach to this effort as depicted in Attachment 1 in the form of a project engagement plan. The FPI Project Manager reported directly to Mr. Paul Fessler to ensure independence of the FPI activities. Routine information and progress updates, in the form of FPI letters, were provided to Mr. Fessler and Mr. Fron. These updates were to ensure Mr. Fessler was informed of FPI activities throughout the entire investigation. These letters also provided a means to track the information required by FPI to conduct the independent analysis and also provide information resulting from the FPI analysis back to Mr. Fessler. This information/status could be used by the Fermi 2 management team as necessary throughout the ongoing investigation.

II Executive Summary

FPI formed an independent team of experts with backgrounds in proven methodologies for performing root cause investigations of this complexity in concert with industry recognized turbine-generator and metallurgical specialists. The teams scope was to conduct an independent assessment of the root cause of failure investigation being conducted by Detroit Edison Company of the Fermi 2 Turbine-Generator event of December 25, 1993. FPI provided an independent review of the root cause evaluation methodology, the final determination of the root cause(s), and corrective actions recommended by the Detroit Edison root cause analysis. FPI conducted independent parallel reviews of the pertinent data and facts, as determined by the Detroit Edison investigation, and arrived at an independent conclusion of the analysis for the root cause of the event which is provided in the conclusion section of this report.

FPI conducted activities both on site at Fermi 2 and offsite at the FPI offices in California. The overall investigation was organized through the use of Fault Analysis Trees, see Attachment 2. The Fault Analysis Trees were formulated using the root cause team experts on site at Fermi. This methodology ensures that all reasonable failure modes are considered in the investigation and that each failure mode is eliminated as a root cause or eventually concluded to be a root cause. This analysis approach ensures that in the event that conclusive evidence cannot be determined to prove only one root cause exists, that corrective actions can be taken to prevent recurrence of all potential root causes determined. This can occur when physical evidence needed to prove a certain root cause is destroyed as a result of the failure. In the situation when multiple potential root causes exist after evaluation of all available evidence then corrective actions to prevent recurrence for each must be implemented or additional testing/monitoring must be performed on the subject equipment on return to service. This was the case with the failure of blade #9. For example, physical evidence was destroyed as a result of the failure that will prevent determining if a lacing spool could have failed to perform it's design function. Therefore, corrective actions must be taken as if this was the primary root cause of the event along with all other additional failure modes remaining.

[redacted]

In the history of the Fermi 2 turbine there have been premature, unexplained failures associated with stages 4, 5, and 7 of the low pressure turbines. Although corrective actions had been taken for those failures it was not assumed that the root cause associated with those earlier failures was not related to the cause of the stage 7 and 8 failures observed during the root cause investigation completed as a result of the December 25, 1993 event. For this reason an added degree of complexity was associated with the root cause of failure of the December 25, 1993 event.

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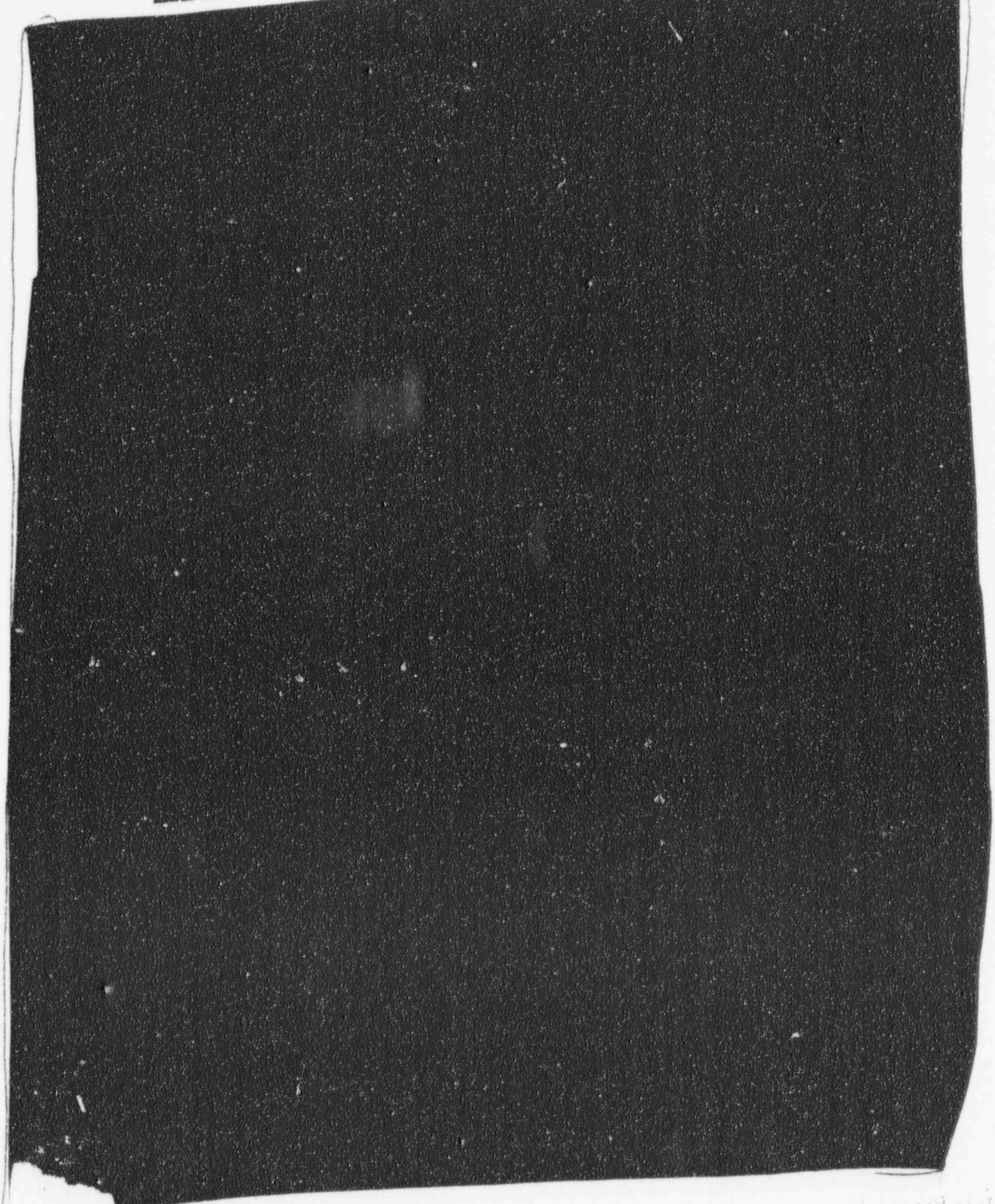


V Event and Analysis Information

At approximately 1315 hours on December 25, 1993, the Fermi 2 plant experienced a turbine-generator failure and automatic reactor trip. The immediate cause of the turbine-generator failure was not known. The failure resulted in extensive damage to the turbine, generator, connected auxiliary piping, bearings, foundations, exciter, and generator to exciter coupling.

The most extensive outwardly visible damage was in the local area of the exciter and coupling to the generator. This included evidence of a generator hydrogen burn, a sheared generator to exciter coupling, destruction of the Number 11 exciter bearing with resultant release of the turning shaft into the exciter stator, and sheared or extracted foundation fasteners.

Obvious visual damage to the LP-3 turbine included broken blading in the L-0 turbine end (front flow) row and damage to the turbine shroud and casing where a portion of the #9 of a blade exited the turbine through the outer casing. Damage to the remaining turbine units was not as extensive and no other blade loss occurred in either the HP, LP1 or LP2 turbines. Sheared and extracted bearing cap fasteners and damaged casing seals were evidenced at all sections of the turbine. In particular there was significant damage to the LP-3 front flow diffuser with large portions missing.

Generator damage included a hydrogen burn with the source being through the generator seals. Seal water, cooling water, and lube oil lines were all damaged where they pulled away from the turbine and generator. Coast down time was approximately 1 minutes 46 seconds to 780 RPM. Ingress of air (decreasing condenser vacuum) into the turbine casing through the hole created by the ejection of blade 9 contributed to this shorter than normal coast down time. Examination of various bearing surfaces revealed damage which was more pronounced on certain bearings of the turbine and generator.

Information from the alarm typer shows that there was a 19 MW electrical disturbance followed by a differential thrust alarm, output breaker opening, and turbine overspeed trip (a more detailed sequence of events is included in Attachment 3). Other plant information does not suggest that the turbine was in an overspeed condition. The turbine manufacturer (GEC) believes and independent analysis supports, that it is possible due to the vibration of the turbine, the mechanical overspeed trip device was actuated. This caused the turbine overspeed trip device to actuate providing the appearance by station alarms and indications that the turbine tripped on overspeed. The conclusion that the turbine-generator rotor system did not overspeed is further supported by vibration recording system analysis and physical measurements of movement of the stub shaft..

There were over one hundred alarms received in the main control room within a period of about 20 seconds as a result of the failure. A partial listing of the alarms is provided in Attachment 3 as well as a complete time line that details the alarms and indications. Following is a list of the most significant alarms and a discussion of why that alarm is considered significant in understanding the event scenario.

A. **Significant Time Line Events** (in seconds)

TIME ZERO (E+-0) Overspeed electrical circuit fault; the first indication of trouble with the unit. This alarm is actually the result of two different speed pick up probes reading a preset difference in speed on the turbine shaft. As described above it has been concluded that this was the result of vibration of the speed pick up probes. The turbine was still synchronized to the grid at this time and overspeed above grid synchronous speed (60 Hz) is considered to be possible only if the unit is not synchronized..

E+0.007 Thrust bearing oil strainer high differential pressure alarm. Normal operation of the turbine maintains this value at about 4.5 psid and the alarm point is 6.0 psid. Reportedly, this alarm comes in any time the unit is upset. This alarm is probably caused by vibration and is significant only from the aspect of an indication of vibration in the turbine generator system.

E+0.037 Number nine bearing (turbine end of generator) alarms on high vibration at a set point of 6 mils. This is a shaft rider type vibration probe reading and the bearing had been running at about 3.8 mils up to about five minutes before time zero when it rose about 0.2 mil. This is the first of many alarms on vibration, see Attachment 4, that tend to increase in magnitude as time increases.

E+0.491 Stator water cooling low flow alarm

E+0.069 Seismic event at alarm setting of 0.01 g - concluded to have been caused by vibration from the turbine.

E+0.125 Turbine trip on mechanical overspeed - determined to have been created by vibration from the turbine. The unit was still synchronized to the grid at this time.

E+0.149 Reactor SCRAM as a result of turbine throttle valve fast closure.

E+0.197 Generator Liquid Leak high alarm - indicates the presence of liquid in the hydrogen gas space of the main generator.

E+1.0 Coast down system activates and starts tracking turbine speed. Speed is recorded at 1800 RPM (still synchronized with the grid).

E+2.0 Speed is recorded at 1800 RPM (still synchronized with the grid).

E+2.761 Generator hydrogen gas pressure low alarm at set point of 65 psig indicates that hydrogen seals have began to fail, concluded to be as the result of vibration.

E+4.0 Speed is recorded at 1800 RPM (still synchronized with the grid).

E+5.547 Condenser low vacuum alarm is received and remaining vacuum is lost very rapidly partially as a result of blade 9 penetrating the casing.

E+8.994 Unit speed commences to drop below 1800 RPM

E+9.777 TG output breakers open

E+9.991 Generator high frequency alarm at set point of 60.5 Hz followed by clearing of the alarm then low frequency at a set point of 59.5 Hz. The estimated maximum speed corresponding to 60.75 Hz. occurred shortly after the generator output circuit breaker opens. This maximum speed is still well below the overspeed trip setpoint.

E+10.0 Turbine building HVAC trips on high differential pressure (pressure inside the building compared to outside the building) at a set point of 3.5 inches water column. The building differential pressure recorder records a rapid drop to a minus .05 inches water column then a rapid spike off scale at positive one inch water column. This information is used to confirm the time and energy associated with the hydrogen burn pressure spike.

E+12.193 First fire alarm comes in

E+20 Number 11 bearing metal temperature alarms on high temperature. This is the first bearing metal temperature alarm to come in. All bearing metal temperatures had tracked steady up to this point.

E+31 Number 11 bearing (exciter bearing) self destructs as evidenced by opening of the bearing metal thermocouple circuit. The most obvious apparent damage was localized in the area of the exciter and included evidence of a hydrogen burn, a sheared generator/exciter coupling, destruction of the Number 11 exciter bearing wit' resultant release of the turning shaft into the exciter stator, and sheared or extracted seal, hold down, and foundation fasteners

Damage to the LP-3 turbine included five broken blades in the L-0 front flow and damage to the turbine shroud and casing where blade #9 exited the turbine on the turbine end, left side of LP-3 hood (north west corner of the hood). Damage to the remaining turbine sections was consequential as a result of the loss of LP3 blading. Each of the three low pressure turbine shafts indicated some degree of bowing/twisting resulting from the vibration and cooldown while not on a turning gear.

Generator damage included a hydrogen burn with the source being through the generator seals and output terminals. Physical evidence revealed indication of burning under the generator, at both ends of the generator and within the exciter enclosure. Review of the U41R801 instrument (Turbine Building Atmosphere Differential Pressure) indicates that prior to the event, the turbine building differential pressure was being maintained at a negative 0.25 inch water pressure. At the event initiation, pressure dropped to a negative 0.5 inches water then spiked off scale at grater than 1.0 inch water positive followed by an immediate return to a 0.25 inch water negative value.

Seal water, cooling water, and lube oil lines were all damaged where they pulled away from the turbine and generator. Precise coast down time is indeterminate but was between two and four minutes aided by loss of condenser vacuum from the blade hole in the LP casing.

One or more turbine blades entered the condenser tube bundles under the LP-3 area and pierced condenser tubes resulting in the introduction of raw cooling water (typically maintained at about 1.5 to 2 cycles of concentration of the Lake Erie cooling water makeup) into the condensate system and ultimately into the reactor vessel.

Flooding of the turbine building basement occurred as the result of ruptured cooling water lines and fire protection sprinkler actuation created by the fire at the generator end. It was estimated that approximately two-thirds of the approximately 500,000 gallons of water in the basement originated from the fire protection system. The flooding created a significant detriment to turbine work as a great deal of resources were required to handle such a volume of water until it was successfully discharged offsite. The condenser was required to be used as a temporary storage facility for the water and therefore the turbine was exposed to a very humid environment until the water issue was resolved. This moisture contributed to the corrosion observed on the rotors when they were removed from the casings.

B. Analysis Data

The pertinent turbine design information is as follows:

Continuous maximum rating (CMR)*	1,100 MWe
Rated speed	1,800 RPM
H.P. Inlet steam pressure	965 psig
at temperature	540 F
L.P. Inlet pressure	219.8 psig
at temperature	513 F
Condenser vacuum	28.5 In Hg
Absolute pressure at turbine exhaust	1.5 In Hga
Final feed temperature	420 F
Maximum overload rating	1200 MWe

* the unit has been recently upgraded by 5% to 1155 MWE

Extraction points:

H.P. cylinder - after stage 5 to #6 H.P.F.W. Heater
H.P. Cylinder exhaust to MSR and #5 H.P.F.W. Heater
North L.P. & south L.P.- before stage 5, to #3 L.P.F.W. Heater
Center L.P.- before stage 3 to #4 L.P.F.W. Heater
North L.P., Center L.P., south L.P.- before stage 7, to #2 L.P.F.W. Heater
North L.P., Center L.P., South L.P.- before stage 8, to #1 L.P.F.W. Heater

The pertinent generator design information is as follows:

Continuous Maximum Rating	1,350 MVA; 1,215 MWe
Power factor	0.9 lagging
Speed at 60 Hz	1800 RPM

already released

Hydrogen pressure	75 psig
Terminal voltage	22,000 volts
Current	33,433 Amps
Design Spec.	ANSI C50.13.1965
Excitation at 1215 MWe	5130 Amp, 566 Volts, 2910 KW
Excitation at 1100 MWe	4755 Amp, 535 Volts, 2546 KW
Hydrogen Space in generator	4,200 SCF
Hydrogen required to fill to 75 psig	29,400 SCFM

[redacted]

[redacted]

[redacted]

the original Fermi-2 blade).

Previous failures at Fermi-2 are as follows:

LP Stage 4

In 1990, a failure of stage 4 blades occurred on LP3 rotor. At the same time the unit was running with LP stage 5 removed and the failures were attributed to the unusually high loading on stage 4 with stage 5 rotor blades removed but with stage 5 diaphragms installed. All stage 4 blades were replaced in 1991. (Blades removed from LP-1 and LP-2 rotors were in good condition.

On the replacement blades the original design was retained but understraps were introduced to provide continuous shroud interconnection for additional damping on all flows.

LP Stage 5

In 1989, following the finding of cracks in the blade roots all stage 5 blades were removed and replaced with root blocks. The failures were attributed to resonance of wheel or packet modes in frequency range where damaging vibrations are not normally encountered. Unusual excitation (possibly water accumulation) was suspected.

same as in A15 report page 16

Reblading took place in 1991 (all flows) with wider (stiffer) blades and understrapped shrouding [redacted]

LP Stage 8

Initially, serious wear of lacing spool rods and the lacing holes was found after prolonged periods of barring. The wear was attributed to "tip rock" of blades during barring. Worn blades were replaced and a program of blade replacement or repair was started. The LP-3 rotor had not yet been fully repaired at the time of the current failure. During RF01, LP-1 stage eight blades were replaced, the best blades from LP-1 were used to replace the worst blades on LP-2 and 3. The removed blades were overhauled and made ready for RF02 when all stage 8 blades on LP-2 were replaced. The removed blades were overhauled and made ready for RF03 when the LP-3 blades were to be replaced. A decision was made to defer the LP-3 blade replacement until RF04. GEC concurred with the provision that the LP-3 blades be inspected during RF03. This inspection was started but did not produce useable evidence that the blades had not degraded to a serious level.

[redacted]

Information from the alarm typer indicates that there was a 19 MW electrical disturbance followed by a differential thrust alarm, output breaker opening, and turbine overspeed trip. The overspeed trip is disputed by the investigators and is not considered to be factual evidence of an actual overspeed event. The turbine Manufacturer (GEC) states that the event was caused by the loss of the L-0 blading resulting in an out-of-balance condition to the remaining rotating element. Each blade weighs about 75 pounds. Loss of 5 blades minus the roots and platforms would result in the loss of about 300 pounds from the wheel.

There is no evidence that the turbine trip was from another source other than overspeed with the conclusion being that the overspeed trip was actuated by vibration of the turbine. Compounding the problem is that some of the turbine and generator instrumentation was damaged within milliseconds of the initiating event.

The generator output breakers opened as the result of reverse current after the turbine throttle valves and intercept valves had closed. There was a minor overshoot of turbine speed when the output breakers opened resulting in a maximum speed of under 61 Hz. This is still well below the minimum overspeed trip setpoint.

The utility staff proceeded to assemble a detailed plan to perform inspections and initial disassembly of the turbine and generator which was accepted by Fermi management and the NRC AIT which allowed the Turbine Generator Assessment Team (TGAT) to proceed.

Working with the staff, FPI assisted in the development of a tree analysis diagram that produced approximately 1500 terminal items that could have contributed to the failure. Because of the detail of the tree, a matrix was developed to allow for computer tracking and focusing of the terminal items to assure that no one detail could be overlooked.

The analysis tree is designed to provide a relatively simple, graphic method of addressing a very complex problem with many possible scenarios. The basic premise is that all possible modes of failure are depicted in the validated diagram and that by addressing each specific terminal item, the true failure mode (proximate cause) of the problem will eventually become obvious. In the final analysis, it is the responsibility of the analysts to provide documentation for each of the specific terminal items that will provide factual evidence that the terminal item is either a contributor to the failure or it is not. However, application of pure logic is an acceptable method for this decision making process, provided, that the logical process is well documented.

The above described process is an indispensable step in arriving at the root causes of a failure. In simpler cases, the process may be totally a mental process, however, it must be conducted. It is important that the difference between a proximate or apparent cause and a root cause be understood if the above process is to succeed.

A apparent or proximate cause of a problem is best described as failure mode identification such as: a bearing fails due to fatigue brought about by axial misalignment of the shaft, or a motor failed due to vibration induced insulation failure brought about by loose slot fillers.

Root causes are, on the other hand, best described as those factors, that if corrected, would have prevented an event (and similar other events) from occurring, such as: poor work practices and defective post maintenance testing that allowed axial misalignment of a shaft to exist. If conditions such as these occur in an isolated case then they would be the root causes, however, if the above practices exist through out the organization, then the root causes would lie in a higher plane, somewhere in the organizational or programmatic areas.

Bolts holding the upper palm key blocks have fractured (reported previously and seen in photographs).

Bolts holding heat shield in place on the rear of number 1 pedestal are hand tight.

Flat bars to which are attached radial datum pegs on each side of the pedestal are loose - i.e. bolts are in place but are slacked off.

2. NUMBER 2 PEDESTAL (HP-LP)

Generally good condition. A number of bolts which attach the front heat shield to the pedestal and the rear bellows unit to the pedestal can be turned by hand but neither unit appears to have moved.

3. NUMBER 3 PEDESTAL (LP1-LP2)

LP2 rear shaft gland bellows fractured. Top half vertical gland assembly to pedestal bolts are hand tight - worst case backed off 1/16".

Number 7 bearing main holding down bolts (4 off) are all hand tight as too are the horizontal joint nuts.

Bolts which hold pedestal down to the foundation are hand tight.

LP3 front shaft gland bellows fractured, bolts sheared and assembly rotated as shown in photographs. Looking through the holes in the top half gland fabrication there are signs of rubbing on the shaft over a 2" arc, but the view is obscured. However the rubs do not appear to be deep.

It was possible to view the number 7 bearing through a hole in the LHS pedestal cover. A sliver of white metal can be seen projecting out of the bearing at approximately 45 degrees to the vertical. There is no sign of blueing of the adjacent shaft and there is no burring of the brass wiper bolted onto the bearing.

Coupling guard looks tight (zero clearance) at TDC -i.e. guard appears to have dropped. Viewed from the hand barring hole the coupling guard appears to be shattered and overlapped in parts. Viewed from the number 8 bearing vantage point the coupling guard horizontal joint is shattered and distorted.

5. NUMBER 5 PEDESTAL

LP3 rear shaft gland bellows fractured. Adjacent oil wiper has a burr at TDC.

Keep half joint bolts missing on right hand side, other half bolts are hand tight.

Main bearing holding down bolts are hand tight and main bolts holding bottom of pedestal to bearing beam are also hand tight.

Number 8 bearing viewed from the left hand side cover plate hole. No signs of any shaft blueing and no white metal can be seen at rear of bearing or in the bottom of the pedestal.
No evidence of BDC rubs on brass wiper bolted on to the rear of bearing 8. Wiper appears to be concentric with the shaft and the bevelled edge of the wiper can be seen.

Number 9 bearing viewed from the rear of the pedestal (both left and right hand) where the rear oil catcher assembly is missing. Condition of the shaft and bearing similar to number 8 bearing. There is a piece of material lying in the bottom of the pedestal which appears to be a piece of machined casting approximately 12-16" long by 2" by 2" with three equidistant spaced holes and fractured ends. Unable to see where this piece came from as the bearing looks intact from the observed angles. NOTE: This piece is lying in the bottom of the pedestal between number 9 bearing (generator front) and the generator end of wall of the pedestal.

The shaft surface between the number 9 bearing and the biological wall is coated with oil. But when the oil is rubbed away the shaft surface is shiny and bright. There are only very slight marks on the shaft surface even though the top and bottom half rear oil catcher assembly was sheared off and thrown clear of the turbine.

6. BEARINGS

These bearings which could be viewed (i.e. 7,8,&9) all appear to be intact and do not appear to have rotated within their mountings.

7. LP3 HOOD

It appears that the two vertical joints have given slightly and allowed small amounts of material/ liquid to seep through (dirty brown in color). The effect is more marked on the rear joint than the front joint. There is no similar effect on the LP2 and LP1 hoods.

An internal inspection of the LP turbines, in preparation for removing the turbine hoods, was conducted on February 1-2, 1994. The inspection report is quoted below:

REFERENCE: Work Req# 000Z940422

LP-3

SOUTH (GENERATOR END) - No damage, but lacing spools are rusting. Very humid.

NORTH END: - East side locating key for outer cylinder has a plate adjacent to it which has rotated, but is still in place under the cylinder.

- East side has hole in sheet metal along hood horizontal joint. This metal is probably a flow guide or joint protection.
- Approximately 13 stage 8 blades adjacent to the 4 or 5 missing blades {confirmed later to be five} are missing the lacing spools. See sketch attached.
- Damaged stage 8 diaphragm, both blades and casting.
- Blades on West side in better shape than on east side.
- West side 2 pieces of debris, one is sheet metal; other may be a small piece of blade (<3 inches x 3 inches)

LP-2

- East side has broken sheet metal cover over outer cylinder horizontal joint bolts. This is a typical maintenance item and would not affect lifting hood. The sheet metal is normally removed later during outer cylinder disassembly.

LP-1

- No damage observed inside hood.

Photographs taken during this inspection disclosed that there were five blades missing, all broken off near the platform.

An inspection performed on 15 February, 1994 of the LP-3, L-0 blades disclosed the following information which is quoted directly:

Blade numbers are from RF-02 per Bill Ackerman, numbered in rotation increasing CCW as viewed from the turbine end.

Blade number 9 is the first failed blade with rotation. High certainty of high cycle fatigue from trailing edge forward {sketch provided showing that crack originated at trailing edge and propagated about 6 inches toward the leading edge and the remaining five inches failed due to overload}.

Fatigue appears to be old, chevroned, oxided, prior to Christmas day.

Blade 8 to 5 appear to be fresh tears due to tensile overload. No obvious fatigue, even at the trailing edge. Crack heights are as follows: 8, 1 1/4"; 7, 1 1/4"; 6, 1 1/2", 5, 1 1/8".

Blade 4 - bent wavy trailing edge 1/2" P-P. 1/2 x 2" high tear in trailing edge at about 24" high, tip to trailing edge. Trailing edge lacing spool is gone, "ripped off".

Blade 3 - cracked at platform radius from trailing edge 1 1/2", angled 45 degrees to tangent of blade. Tear in trailing edge 24" height. Tip bent about 3" against rotation. Crack is 1 1/4" from platform of leading edge of blade 2. Crack is a tear. Appears {that the blade} is untwisted about 30 degrees.

Blade 2 - tip bent against rotation about 3" over last foot, also untwisted about 30 degrees.

Cracks in blades 1 and 3 result fro. , movement towards generator.

Blade 1 - crack 1 1/2" from platform about 4 3/4" long from trailing edge tear. Tip also bent against rotation about 6" and untwisted about 30 degrees.

Blades 64-59 have tip damage, relatively minor in comparison, also missing lacing spools.

Wheel position 27 on the turbine end blade marked "turb. cycl 1 blade 48", intact lacing spool appears to be in place, has a ding in the trailing edge at 4" high, approximately 2" high by 1/2" deep.

Fluorescent magnetic particle inspection, performed on 26 February, 1994 of the front flow L-0 row of blades disclosed that there were additional indications on blades as follows:

Blade 2,3,4 have multiple intermittent linear indications in and propagating from the lacing spool holes. Maximum length of 7/8".

Blade 41,42,43 have one linear indication within the impacted area located approximately 1/4" from then platform on the trailing edge of the blade.

Blade 64 has multiple intermittent linear indications on the convex side of the air foil, approximately 1" from the platform oriented perpendicular to the longitudinal axis of the air foil. The indications start 1" from the trailing edge to 1 3/8", total length of 1 1/4".

Blades 1 and 3 had protective tape covering an area from the platform to approximately 3" above the platform (installed to protect known indications from dye contamination).

Flourescent magnetic particle inspection, performed on 26 February, 1994 of the generator end L-0 row of blades disclosed that there were indications on blades as follows:

Blade 53 has two linear indications on the convex side of the air foil, 5/8" from the platform oriented perpendicular to the longitudinal axis of the air foil. One indication is 1 1/4" TO 2 1/4" from the trailing edge (total length 1"), the second indication is 3 3/8" to 4 1/4" from the trailing edge (total length 7/8"). The location of these indications are where the platform to the air foil. This area has surface irregularities (ridges) that the magnetic particles are held to. Other blading have these same surface irregularities but did not show indications by MT. These indications were later polished out and were determined to be inconsequential

VI References

1. Metallurgical Analysis of Fermi 2 LP3 Eighth Stage Turbine Blading, Detroit Edison Technical and Engineering Services, Report No. 94V70-13, dated June 20, 1994

2. Failure Diagnostic Guidebook, 1991 Failure Prevention Inc., Chong Chiu, Ph.D.

3. Fermi 2 Turbine Generator Assessment Team Action Plan, January 14,1994 Rev.1

4. Root Cause Guidebook, 1989 Failure Prevention Inc., Chong Chiu, Ph.D.

5. Steam Turbine Blades: Considerations in Design and a Survey of Blade Failures, EPRI CS-1967 Topical Report August 1981

6. Survey of Steam Turbine Blade Failures, EPRI CS-3891 Final Report March 1985

7. Summary of FPI Metallurgical Analysis of Stage 8 Failures by Dr. Mostafa

5. Memo: Mr. Ralph Ortolano to Mr. J. Summy, Subject: Input for Root Cause Analysis Report dated July 25, 1994

Attachment 1

Fermi Independent Root Cause Analysis Engagement Plan

ENGAGEMENT PLAN
FOR THE FERMI ROOT CAUSE ANALYSIS OF
TURBINE GENERATOR EVENT OF DECEMBER 25, 1993

Purpose:

Provide the outline that will be followed to ensure FPI satisfies the requirement of successfully assisting Detroit Edison Company perform a detailed root cause analysis of the turbine generator event that occurred on December 25, 1993. Per the Fermi Investigation Manager's request FPI will perform this as an independent analysis team.

Scope:

FPI will perform an independent review of the root cause analysis of the turbine generator fault that occurred on December 25, 1993. This by request of the Fermi Team Manager involves the following:

- o Independently monitor initial Fermi 2 Turbine-Generator Assessment Team (TGAT) activities and make recommendations to Mr. Len Fron, Team Manager.
- o Independently assess the TGAT Action Plan and Attachments used to perform inspections and provide feedback to the Team Manager.
- o Assist in the preparation of a detailed Failure Modes chart for determining the various failure modes to be investigated in completing the root cause.
- o Independently assess information, to be provided by the TGAT, to ensure root cause efforts are rigorous. This will include items such as the event time line, machinery history, industry information pertinent to the event, etc.
- o Perform independent analysis necessary to determine the root cause(s) of the turbine-generator failure. These analyses will typically consist of metallurgical analysis of failed components, chemical analysis, stress analysis, model projections, etc.
- o Provide a detailed report of the FPI activities with an explanation of the root cause(s) and recommended corrective actions to prevent recurrence.

Background:

At approximately 1315 hours on December 25, 1993, the Fermi 2 plant experienced a turbine-generator failure and automatic reactor trip. The immediate cause of the turbine-generator failure is not known. The failure resulted in extensive damage to the turbine, generator, connected auxiliary piping, bearings, foundations, exciter, and generator to exciter coupling.

The most extensive outwardly visible damage is in the local area of the exciter and coupling to the generator. This includes evidence of a hydrogen explosion and fire, a sheared generator to exciter coupling, destruction of the after (outboard) exciter bearing with resultant release of the turning shaft into the exciter stator, and sheared or extracted foundation fasteners.

Obvious visual damage to the LP-3 turbine includes broken blading in the L-0 generator end row and damage to the turbine shroud and casing where at least one portion of a blade exited the turbine through the outer casing. Damage to the remaining turbine units is unknown but sheared and extracted bearing cap fasteners and damaged casing seals is evidence of some damage to all sections of the turbine.

Generator damage includes a hydrogen burn with an apparent source through the generator seals. Seal water, cooling water, and lube oil lines were all damaged where they pulled away from the turbine and generator. This resulted in loss of these services while the unit was still rolling. Coast down time is indeterminate but appears to have been approximately 4 - 5 minutes, probably without sufficient lubricating oil or seal oil.

Information from the alarm typer shows that there was a 19 MW electrical disturbance followed by a differential thrust alarm, output breaker opening, and turbine overspeed trip. Other plant information does not suggest that the turbine was in an overspeed condition. The turbine manufacture (GEC) believes it is possible that due to the vibration of the turbine, the mechanical overspeed trip device was actuated, thus causing the turbine to trip on overspeed. GEC also believes that the event was caused by the loss of the L-0 blading (it is not known how many blades have separated) which resulted in an out-of-balance condition to the remaining rotating element. Compounding the problem with respect to data from the turbine is the fact that much of the turbine and generator instrumentation was damaged within a short period of the event initiation.

FPI has been requested by the utility to provide an oversight review of the root cause analysis as conducted by the plant staff team. Jeff Summy and Don Kidder arrived at the plant Monday, January 3, 1994 and began this process. Mr. Len Fron has been designated as the Manager for the Turbine-Generator root cause. During the first week, the activities were mostly related to review of team formation and action plan strategy. The entire turbine-generator and condenser areas are under quarantine by the NRC AIT and therefore inspection and repair activities will proceed slowly until root cause is understood.

It is clearly the desire of Fermi Management to determine the root cause and implement corrective actions to prevent recurrence before the unit is restarted. This is expressed repeatedly to the team by Mr. Fron and is in the Mission and Goals of the TGAT Action Plan.

Approach:

Overall Project Coordination will be through either the Project Director, Jeff Summy, or the Assistant Project Director, Don Kidder. These individuals should be informed of any significant issues, difficulties, or requirements of FPI Investigators assigned to the Fermi 2 Turbine Generator Root Cause Project.

Since a firm schedule of activities is not known at this time it is requested that the following schedule be used as a "flexible" guide to plan from. Routine communications will be provided from Don or Jeff to the FPI team to ensure all personnel are aware of current plans.

Date(s)	Activity	Investigator
January 12-13	Condenser entry, inspect remove loose debris.	Kidder / Summy
January 14-15	Degas Generator	Kidder
January 16-19	Initial turbine bldg walk down, catalog, lab analysis	Mostafa / Summy
January 20-24	Initial turbine, generator, exciter inspections	Ortolando / Summy
January 25-29	Turbine, generator, exciter disassembly	Ortolando / Chen / Kidder
February 1-10	Complete material analysis	Mostafa / Kidder
February 11-16	Complete Root Cause Analysis	Chiu (Team)

Note: It will be determined at the actual time that a particular activity occurs what resources will be required on-site and for what purpose.

A project coordination meeting / conference call will be conducted with all project participants on Friday January 14, 1994. A review of the known facts will be conducted and discussed with the team. The preliminary schedule will be discussed to ensure the correct resource(s) are listed for the activity and that the resource will be available at that time. A review of the Failure Modes chart constructed by Don Kidder will also be conducted to ensure all failure modes are included in the investigation.

If specific data is needed when you are not actually on-site please contact Don or Jeff so that we are not impacting the Fermi site personnel. It is requested that each investigator keep a log of their activities associated with this project and specifically those activities that are conducted on-site. Please provide a copy of those log sheets with a copy of your time sheets to Jeff at the San Clemente office at the end of each pay period. Each investigator will be required to submit a report at the completion of the project detailing their involvement, conclusions, recommendations, and any information necessary to support the complete root cause effort.

The above activities will be conducted at the Fermi site with the exception of material analysis which will most likely be conducted at the Detroit Edison Analysis Laboratory in Detroit.

Expectations and Deliverables:

It is expected of the FPI Fermi 2 Turbine-Generator Root Cause Failure Team to work closely in conjunction but in an independent fashion with respect to the root cause analysis with the Fermi TGAT. It is further expected that the FPI Team will support the schedule as defined by Detroit Edison.

The FPI Team will provide a detailed and accurate root cause analysis using all available technologies, industry experience, and FPI resources in a cost effective manner. Based on the root cause(s), recommended corrective actions will be provided which if adopted will prevent or mitigate recurrence.

Prepared by: Jeffrey S. Summy Date: 1/12/94

Jeffrey S. Summy

Attachment 2

Fault Analysis Tree Matrix

Attachment 3
Timeline of Events

FERMI-2 MTG EVENT TIME LINE

TIME 1315	EVENT	TIME LAPSE
47.406	O/S ELCT CKT FAULT	0
47.413	THRUST BEARING STRAIN HI D/P	0.007
47.443	BRG 9 HI VIB ON SHAFT @ 6MIL	0.037
47.475	SEISMIC EVENT S.P. 0.01 G	0.069
47.482	BRG 8 HI VIB ON SHAFT AT 6 MIL	0.076
47.514	BRG 4 HI VIB ON SHAFT AT 6 MIL	0.108
47.526	BRG 11 ON LOAD ON PED AT 5 MIL	0.12
47.529	UA THROTTLE VLV FAULT	0.123
47.53	BRG 11 HI VIB ON PED AT 3 MIL	0.124
47.531	TURBINE O/S MECH TRIP 110%	0.125
47.532	BRG 11 RUN UP ON PED AT 5 MIL	0.126
47.534	BRG 5 HI VIB ON SHAFT AT 6 MIL	0.128
47.538	BRG 8 ON LOAD ON SHADFT AT 10 MIL	0.132
47.543	TURBINE TRIP RELAY TRIPPED	0.137
47.544	TURB CONTROL VLV FAST CLOSE	0.138
47.555	RPS ACTUATION	0.149
47.558	BRG 7 HI VIB ON SHAFT AT 6 MIL	0.152
47.582	BRG 10 HI VIB ON PED AT 3 MIL	0.176
47.587	ELECTRIC GOVERNOR TROUBLE	0.181
47.591	BRG 9 ON LOAD ON SHAFT AT 10 MIL	0.185
47.598	BRG 3 HI VIB ON SHAFT AT 6 MIL	0.192
47.599	BRG 8 RUN UP ON SHAFT AT 10 MIL	0.193
47.6	BRG 9 RUN UP ON SHAFT AT 10 MIL	0.194
47.601	BRG 5 ON LOAD ON SHAFT AT 10 MIL	0.195
47.603	GEN LIQUID LEAK HI ALARM	0.197
47.606	BRG 5 RUN UP ON SHAFT AT 10 MIL	0.2
47.617	BRG 1 HI VIB ON PED AT 3 MIL	0.211
47.622	BRG 7 RUN UP ON SHAFT AT 10 MIL	0.216
47.623	BRG 4 ON LOAD ON SHAFT AT10 MIL	0.217
47.624	BRG 7 ON LOAD ON SHAFT AT 10 MIL	0.218
47.632	BRG 4 RUN UP ON SHAFT AT 10 MIL	0.226
47.637	BRG 2 ON LOAD ON SHAFT AT 10 MIL	0.231
47.648	BRG 2 RUN UP ON PED AT 5 MIL	0.242
47.654	BRG 3 RUN UP ON SHAFT AT 10 MIL	0.248
47.655	BRG 10 RUN UP ON PED AT 5 MIL	0.249
47.664	BRG 10 ON LOAD ON PED AT 5 MIL	0.258
47.691	U/A HP STOP VLV FAULT	0.285
47.697	MS BYPASS VLVS OPEN	0.291
47.738	BRG 1 RUN UP ON PED AT 5 MIL	0.332
47.739	BRG 1 ON LOAD ON PED AT 5 MIL	0.333

FERMI-2 MTG EVENT TIME LINE

TIME 1315	EVENT	TIME LAPSE
47.79	M.S. STOP VLVS CLOSED	0.384
47.682	BRG 3 ON LOAD ON SHAFT AT 10 MIL	0.276
47.791	M.S. STOP, THROTTLE VLV TRIP	0.385
47.871	BRG 9 HI VIB ON SHAFT AT 10 MIL	0.465
47.897	STAT WAT LOW FLOW	0.491
47.956	BRG 10 HI HI ON PED AT 4 MIL	0.55
47.975	BRG 11 HI HI ON PED AT 4 MIL	0.569
48.073	BRG 1 HI HI ON PED AT 4 MIL	0.667
48.084	BRG 8 HI HI ON SHAFT AT 12 MIL	0.678
48.125	BRG 4 HI HI ON SHAFT AT 12 MIL	0.719
48.155	6S FD HTR ESS CHECK VLV CLOSED	0.749
48.156	BRG 5 HI HI ON SHAFT AT 12 MIL	0.75
48.165	BRG 7 HI HI ON SHAFT AT 12 MIL	0.759
48.19	BRG 2 HI HI ON SHAFT AT 12 MIL	0.784
48.247	BRG 3 HI HI ON SHAFT AT 12 MIL	0.841
48.316	DETRAIN TK TURB END HI/LO	0.91
48.356	6N FD HTR CHECK VLV CLOSED	0.95
48.406	COAST DOWN SYSTEM STARTS	1
48.406	TURBINE AT 1800 RPM	1
48.416	LP STOP/IV 3-4 TRIP	1.01
48.432	4S FD HTR CHECK VLV CLOSED	1.026
48.447	4N FD HTR CHECK VLV CLOSED	1.041
48.458	INTERCEPT VLV FAULT	1.052
48.516	3N FD HTR CHECK VLV CLOSED	1.11
48.635	4N FD HTR CHECK VLV CLOSED	1.229
49.125	LOSS H2 SEAL OIL	1.719
48.705	3S FD HTR CHECK VLV CLOSED	1.299
48.989	H2 SEAL OIL PUMP AUTO START	1.583
49.406	TURBINE AT 1800 RPM	2
49.125	H2 SEAL OIL PUMP AUTO START	1.719
49.454	RECTIFIER COOL LINE #4 LOW FLOW	2.048
49.515	LP STOP/1-3-5 TRIP (E. MSR)	2.109
49.573	STAT COOL PUMP AUTO START	2.167
49.765	SEAL OIL/GAS DIFF PRESS FAULT	2.359
49.77	SEAL OIL/GAS DIFF PRESS LOW	2.364
50.058	5N FD HTR CHECK VALVE CLOSED	2.652
50.167	H2 GAS PRESSURE LOW	2.761
50.311	GLAND STM PRESS	2.905
50.991	LP EXHAUST SPRAYS ON	3.585
51.185	LP EXHAUST SPRAY EMERG PUMP ON	3.779

FERMI-2 MTG EVENT TIME LINE

TIME 1315	EVENT	TIME LAPSE
51.396	SEAL OIL STRAIN HI DP	3.99
51.406	TG IS AT 1800 RPM	4
51.556	RECTIFIER COOL LINE #4 LOW FLOW	4.15
51.559	RECTIFIER COOL LINE #4 LOW FLOW TRIP	4.153
52.19	BRG 6 SHAFT DIFF EXPANSION NEGATIVE	4.784
52.599	THRUST BRG OIL PRESS LOW <8 PSIG	5.193
52.72	SEAL OIL STRAIN HI DIFF PRESS	5.314
52.953	CONDENSER PRESS HIGH	5.547
53.091	H2/H20 DIFF PRESS LOW	5.685
53.572	CONDENSER HI FAULT 4.5 " Hg	6.166
53.766	EXHUAST SPRAY STRAINER HI DP	6.36
54.099	THRUST BRG NEG WEAR PRE-TRIP	6.693
55.212	AVR CHAN B TRIP	7.806
55.311	BRG OIL PRESS LOW FAULT <10 PSIG	7.905
55.351	TURBINE OIL PUMP AUTO START 10 PSIG FALLING	7.945
55.644	TURBINE EMERG OIL PUMP START 10 PSIG FALLING	8.238
55.658	AVR ON MANUAL CONTROL	8.252
55.992	BRG 1 SHAFT DIFF EXPANSION POS	8.586
56.367	BRG 6 SHAFT DIFF EXPANSION NEG	8.961
56.4	TG AT LESS THAN 1800 RPM	8.994
57.161	GEN DIFF RELAY STRING OPERATED	9.755
57.183	345 KV BREAKER POS C.F. OPEN	9.777
57.184	345 Kv BREAKER POS C.M. OPEN	9.778
57.229	E. STAT COOLING PUMP OFF	9.823
57.238	W. STAT COOLING PUMP OFF	9.832
57.308	GEN FIELD BKR OPEN	9.902
57.397	GEN FREQ HI/LO	9.991
58.036	STAT WTR FLOW LO FAULT	10.63
58.53	GEN INLET WTR TEMP HI	11.124
59.382	5S FD HTR CHECK VLV CLOSED	11.976
59.599	FIRE ALARM	12.193
59.694	GEN FREQ HI/LO	12.288
59.714	RECTIFIER LINE 1 LO FLOW FAULT	12.308
59.815	5N FD HTR CHECK VLV CLOSED	12.409
59.945	RECTIFIER COOL LINE 1 LO FLOW TRIP	12.539
60.167	RECTIFIER COOL LINE 4 LO FLOW TRIP	12.761
60.194	RECTIFIER COOL LINE 3 LO FLOW TRIP	12.788

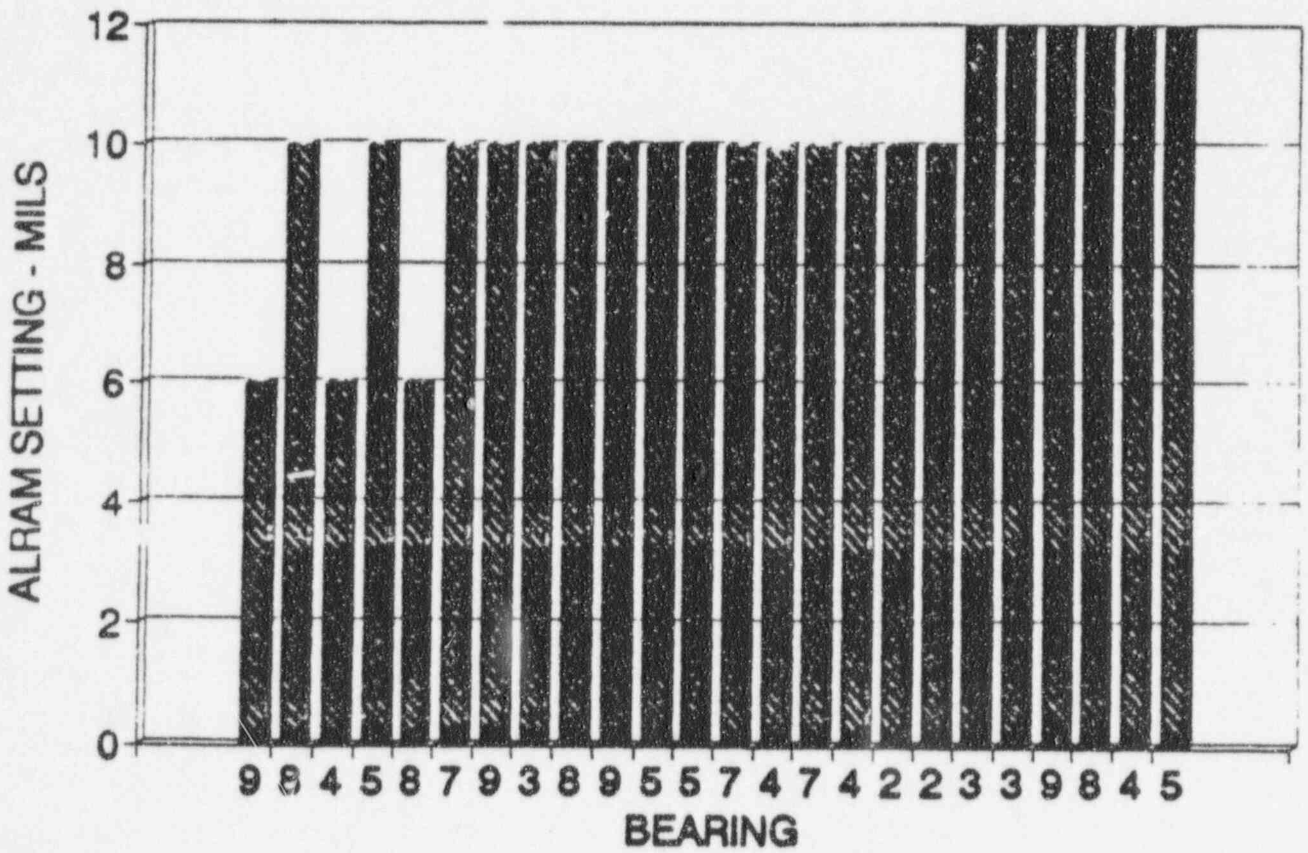
Attachment 4

Turbine Vibration Alarm List

TIME		BEARING VIBRATION DATA EVENT
47.443	0.037	BRG 9 HI VIB ON SHAFT @ 6MIL
47.482	0.076	BRG 8 HI VIB ON SHAFT AT 6 MIL
47.514	0.108	BRG 4 HI VIB ON SHAFT AT 6 MIL
47.526	0.128	BRG 11 ON LOAD ON PED AT 5 MIL
47.53	0.132	BRG 11 HI VIB ON PED AT 3 MIL
47.532	0.152	BRG 11 RUN UP ON PED AT 5 MIL
47.534	0.185	BRG 5 HI VIB ON SHAFT AT 6 MIL
47.538	0.192	BRG 8 ON LOAD ON SHADFT AT 10 MIL
47.558	0.193	BRG 7 HI VIB ON SHAFT AT 6 MIL
47.582	0.194	BRG 10 HI VIB ON PED AT 3 MIL
47.591	0.195	BRG 9 ON LOAD ON SHAFT AT 10 MIL
47.598	0.2	BRG 3 HI VIB ON SHAFT AT 6 MIL
47.599	0.216	BRG 8 RUN UP ON SHAFT AT 10 MIL
47.6	0.217	BRG 9 RUN UP ON SHAFT AT 10 MIL
47.601	0.218	BRG 5 ON LOAD ON SHAFT AT 10 MIL
47.606	0.226	BRG 5 RUN UP ON SHAFT AT 10 MIL
47.617	0.231	BRG 1 HI ON PED AT 3 MIL
47.622	0.242	BRG 7 RUN UP ON SHAFT AT 10 MIL
47.623	0.248	BRG 4 ON LOAD ON SHAFT AT10 MIL
47.624	0.276	BRG 7 ON LOAD ON SHAFT AT 10 MIL
47.632	0.465	BRG 4 RUN UP ON SHAFT AT 10 MIL
47.637	0.678	BRG 2 ON LOAD ON SHAFT AT 10 MIL
47.648	0.719	BRG 2 RUN UP ON SHAFT AT 10 MIL
47.654	0.75	BRG 3 RUN UP ON SHAFT AT 10 MIL
47.655	0.759	BRG 10 RUN UP ON PED AT 5 MIL
47.664	0.784	BRG 10 ON LOAD ON PED AT 5 MIL

47.738	0.841	BRG 1 RUN UP ON PED AT 5 MIL
47.739		BRG 1 ON LOAD ON PED AT 5 MIL
47.682		BRG 3 ON LOAD ON SHAFT AT 10 MIL
47.871		BRG 9 HI VIB ON SHAFT AT 10 MIL
47.956		BRG 10 HI HI ON PED AT 4 MIL
47.975		BRG 11 HI HI ON PED AT 4 MIL
48.073		BRG 1 HI HI ON PED AT 4 MIL
48.084		BRG 8 HI HI ON SHAFT AT 12 MIL
48.125		BRG 4 HI HI ON SHAFT AT 12 MIL
48.156		BRG [illegible] HI HI ON SHAFT AT 12 MIL
48.165		BRG 7 HI HI ON SHAFT AT 12 MIL
48.19		BRG 2 HI HI ON SHAFT AT 12 MIL
48.247		BRG 3 HI HI ON SHAFT AT 12 MIL

SHAFT VIBRATION ALARMS
IN ORDER OF OCCURANCE



PEDESTAL VIBRATION ALARMS
IN ORDER OF OCCURANCE