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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

OF THE RESTART ISSUES OF THE MAIN STEAM TURBINE

DETROIT EDISON

ENRICO FERMI NUCLEAR PLANT UNIT 2

DOCKET NUMBER 50-341

1.0 INTRODUCTION

On December 25, 1993, the main turbine failed at the Fermi 2 nuclear power plant resulting in damages to the exciter, the generator, condenser tubes, and the piping of secondary systems. The unit shut down safely; however, an oil and water mixture from sheared oil and water lines and activation of the fire suppression system flooded the basement of the turbine and adjacent radwaste buildings.

The rupturing and damage to condenser tubes during the turbine failure event resulted in treated circulating water from Lake Erie being dumped to the condenser hotwell. The excess of water in the hotwell was routed to the condensate storage tank (CST) degrading its water quality. This water was subsequently transferred to the reactor vessel by the reactor core isolation cooling system and standby feedwater system in order to maintain water inventory. This caused a significant chemistry transient within the reactor vessel.

On December 28, 1993, the Region III Administrator issued a Confirmatory Action Letter (CAL) to Detroit Edison (DECO), the licensee, and requested specific action items to be addressed before startup. These actions included completing an investigation to determine the root cause(s) of the event and subsequent equipment failures; completing an evaluation of the effects of the abnormal water chemistry on the fuel and reactor internals; instituting in situ quarantine of components and equipment for NRC Augmented Inspection Team (AIT) investigation; submitting the plan for investigation of the event, recovery of the facility and proposed corrective actions to the NRC Region III office; providing documentary evidence of the investigation efforts to the AIT; and having event on-shift staff members available for interviews. The CAL further stated the understanding that restart of the Fermi 2 facility would not occur until the licensee had informed the Regional Administrator of the results of its investigation and its corrective actions.

The licensee responded to the CAL by letters dated August 24, and October 13, 1994, [12 and 13] providing the results of its internal investigation of the root causes of the event, the corrective actions taken to restore the turbine to service, and the effects of the abnormal water chemistry on the reactor internals and fuel. Additionally, the licensee provided a revised missile hazards analysis to address the new turbine configuration (7th and 8th stage blades removed and pressure plates installed on all three low pressure turbines) and commitments related to reactor chemistry and turbine vibration monitoring.

The Regional Administrator, in accordance with NRC Inspection Manual Chapter 0350, established a Restart Panel to track the licensee's activities. The Restart Panel developed a Restart Action Plan to document resolution of restart issues related to the event. To address the NRC's concerns, DECO has repaired the turbines, refurbished the stator and rotor in the generator, replaced the exciter, modified water chemistry, and completed other system modifications. Additionally, the licensee has performed walkdowns to assess the structural damage resulting from the event and has completed necessary repairs.

The objective of this safety evaluation is to assess (1) the root causes of the turbine failure, (2) the corrective actions performed by DECO to address the root causes, (3) the condition of the repaired turbines, (4) the tests and inspections performed on the turbines, and (5) the turbine missile analysis. The safety evaluation also assesses the licensee's analysis and corrective actions related to the chemistry transient and effect of abnormal chemistry on reactor vessel internals. Additionally, the safety evaluation assesses the licensee's analysis of the structural damage resulting from the event and related corrective actions and documents resolution of Restart Action Plan items assigned to the Office of Nuclear Reactor Regulation.

2.0 DISCUSSION AND EVALUATION

2.1 Root Causes

Fermi Unit 2 uses one high pressure (HP) and three double-flow low pressure (LP) turbines manufactured by GEC Alsthom (GECA) of Great Britain. The turbine-generator set is favorably oriented and operated at 1,800 revolutions per minute (rpm). Each LP rotor has six shrunk-on disks per steam flow, a total of 12 disks, symmetrically fitted on the shaft. There are eight rows (stages) of blades that attached to the six disks per steam flow. Two rows of blades are attached to each of disk 1 and 2 and a single row of blades is attached to disk numbers 3 through 6.

DECO reported that the failure of blade number 9 of the stage 8 blades in the LP3 rotor initiated the event. It caused the failure of four adjacent blades. One blade fragment was ejected from the turbine casing. The failed blades created unbalanced loads on the turbine rotors and resulted in excessive vibration, which in turn damaged the generator, the exciter, and other systems and components.

DECO; Failure Prevention International (FPI), a DECO contractor; and GECA conducted independent investigations of root causes as discussed in references [1, 2, 3]. After investigating 1,600 possible contributors, DECO identified the following 7 probable causes that led to the failure of blade number 9 [4, 5, 6, 13]:

(1) steam path water caused by water accumulation and water induction; (2) torsional resonance of the turbine rotors caused by electrical system disturbance; (3) physical characteristics and/or fabrication defects of blade number 9; (4) steam/water chemistry that contributed to corrosion fatigue of the blades; (5) higher loading on blades caused by low condenser back

pressure; (6) boiling water reactor (BWR) environment having a high level of oxygen in the steam; and (7) loss of the lacing spool that would allow blade number 9 to become free standing and possibly more susceptible to excitation.

Corrective Actions

To address water accumulation, DECO modified drain holes at stages 7 and 8, and the low point drains in the extraction steam line to feedwater heaters 1 and 2. This will allow water in the turbine to drain properly. DECO will review the extraction steam and feedwater heater drain systems (north, center and south feedwater heaters 1 and 2) for conformance with ANSI/ASME Standard TDP-2-1985 and will implement appropriate changes during cycle 5. In addition, DECO will test the capability of moisture removal of the moisture separator reheaters and, if required, make appropriate changes during RFO 5.

DECO's consultant performed analysis to confirm that additional rotor stresses due to torsional vibration would not be a concern in the post startup configuration of the turbine generator rotor system. All airfoils in stages 7 and 8 will be removed; therefore, material defects in the stages 7 and 8 blades will also not be a concern. The removal of airfoils will also eliminate the concerns relating to lacing spools and removes the blades most sensitive to low condenser back pressure. Because the effect of steam/water chemistry and BWR environment to reduce fatigue strength of airfoils is most prominent in stages 7 and 8 and these airfoils are being removed, these two contributors will not be a significant concern.

2.2 Condition of the Turbines Before Startup

DECO has installed pressure plates for 12 diaphragms (stationary blades) at stages 7 and 8 in the LP rotors, performed nondestructive examinations (NDE) of HP and LP rotors, reduced the deformation in all three LP rotors, and implemented turbine vibration monitoring guidelines.

Pressure Plate Design

The purpose of the pressure plates is to allow temporary turbine operation while maintaining the same level of the pressure drop to avoid overloading the blades in neighboring stages. The pressure plate must (1) pass the same amount of steam flow as the stage it is replacing; (2) meet any extraction pressure requirements between stages that the plates are replacing; and (3) match operating pressure at the exit of the upstream rotating blades and at the inlet of the downstream stationary blades.

GECA designed the pressure plates. Each pressure plate consists of two half "doughnut" plates, fabricated from low alloy carbon steel, A387-87 Grade 22, Class 2 material. Stage 7 pressure plates have 17,630 holes of 0.5 inch in diameter. Stage 8 plates have 18,636 holes of 0.75 inch in diameter. The pressure plates are fastened to the turbine casing at the existing diaphragm grooves. Westinghouse reviewed the capability of the pressure plate design to duplicate the designed turbine thermodynamic conditions and the structural integrity of the plate. Westinghouse concluded that the plate design was conservative and acceptable [7].

DECO requested MPR Associates to perform a survey of pressure plates used in the industry. DECO also requested FPI to verify the pressure plate design, to review the Westinghouse evaluation of the GECA design, and to review the MPR industry experience survey. FPI responded with its verification and acceptance by letter dated June 15, 1994 [8]. In addition, DECO contacted individual utilities that use pressure plates at stages 7 and 8 locations to gain additional insights on their performance. DECO found that pressure plates have been used in LP turbines at 12 nuclear power plants. In each case, the pressure plate performance has been satisfactory. DECO stated that if pressure plates failed they would fall into the condenser and not become turbine missiles.

DECO contracted Heat Exchanger Systems, Inc. (HESI) to verify the adequacy of condenser tube support spacing under the increased steam flow that will result from the pressure plates. HESI's analysis [9] showed that the increased steam flow to the condenser will not require any additional anti-vibration support for the condenser tubes.

Nondestructive Examination (NDE) of HP and LP Turbine Rotors

DECO performed visual examinations and magnetic particle tests (MT) on all exposed surfaces of HP and LP rotors. This included examination of blades, disks, shrouds, and disk faces. In addition, DECO performed ultrasonic tests (UT) on blade roots and disk heads for stages 4 through 8 in all LP rotors, on disk bores and dowel holes in LP rotors, and on disk bores of the HP rotor. DECO did not perform UT tests on disks and blades of stages 1, 2, and 3 in the LP rotors because DECO judged that visual and MT results of disks and blades of these stages were adequate.

For the HP rotor, DECO found indications on the shroud of stage 1 blades on the generator end. The indications were ground out and reinspected. Based on the favorable results of the inspection, DECO concluded that the HP turbine rotor could be returned to service.

For the LP rotors, DECO found disk bores and dowel holes to have satisfactory results. Indications were found in the balance holes of stages 2, 4 and 5 disks and in the steeples of the stage 5 disk in the LP3 rotor. The indications were ground out and components were reinspected with acceptable results. Indications were also found in the roots of many stage 7 blades in the LP2 and LP3 rotors. They were not of concern because the 7th stage blades were removed.

DECO found indications on the steeples of the stage 7 disks in all three LP rotors. Most of the indications were ground out. Indications that remained in the steeples were judged to be insignificant because the maximum depth is 0.005 inch. It is anticipated that the remaining indications will not grow significantly because the 7th stage blades were removed. In addition, all three LP rotors will be replaced at the end of the upcoming fuel cycle, which is about 18 months from the restart.

Turbine Shaft

As a result of the excessive turbine vibration, the shafts of all three LP rotors were deformed with a slight bow or bend at the center plane between the journals. The HP turbine rotor was not deformed. The deformations were 16 mils, 18 mils, and 33 mils for the LP1, LP2, and LP3 rotors, respectively. These deformations were small compared to the average rotor span of 318 inches. To correct the shaft deformation, DECO contracted Westinghouse to straighten the shaft by spin balancing the rotors. LP1 and LP 2 rotors were corrected to 10 mils and 12 mils, respectively. The LP3 rotor had relatively high deformation. As a result, it had to be heated to loosen the disks before spin balancing. The final deformation for the LP3 rotor was 12 mils. The faces of shaft couplings were machined so that rotors of all turbines and the generator can be aligned properly.

Turbine Vibration Testing and Monitoring

Westinghouse tested each LP rotor at 120% of rated speed and spin balanced each rotor at 100% of rated speed. The shaft vibration after spin balancing each rotor was less than 2.0 mils peak-to-peak. If required (see table below), DECO will spin balance the entire turbine-generator set during startup at the Fermi plant. DECO stated that the vibration during the initial startup could reach up to 10 mils at rated speed before synchronization. With synchronization and load increase, DECO anticipated that the normal vibration will be similar to that experienced during operating cycle 4 (refueling outage (RFO) 3 to December 25, 1993), which was less than 5 mils at full load, steady-state conditions.

DECO has implemented procedures to monitor turbine vibration and to manually trip the turbine. During the startup, DECO intends to use the following vibration guidance which is based on previous operating experience and manufacturer and insurer recommendations. The shaft vibration displacement, d, is measured at 1,800 rpm steady-state conditions, peak-to-peak:

$d \leq 4$ mils	No action required.
4 mils $< d \leq 7$ mils	Compute the amount of the shot (weights) to balance the shaft and install the shot during a future outage when the turbine-generator set is off the line for greater than 24 hours.
7 mils $< d \leq 9$ mils	Compute the amount of the shot (weights) to balance the shaft and schedule the installation of the shot. The turbines will be shut down within 6 months for the installation of the shot.
9 mils $< d <$ 14 mils	Obtain vibration data. The turbine can remain in operation for not more than 30 minutes for data acquisition; then take action to reduce vibration.
$d >$ 14 mils	Shut down immediately.

An automatic turbine vibration trip will be activated 60 to 90 days after near full power operation. This is to evaluate the performance of vibration monitoring instrumentation and avoid unnecessary turbine trips from spurious transients during startup, which could lead to unnecessary reactor scrams.

2.3 Turbine Missile Analysis

DECO revised the original turbine missile analysis to consider the consequences of turbine overspeed because of the removal of the 7th and 8th stage blades. In the revised missile analysis [10], DECO used a maximum overspeed of 3,280 rpm, which is higher than 3,000 rpm used in the original missile analysis. Otherwise, the revised analysis used the same assumptions as in the original analysis, which is based on the worst case disk failure. DECO used the weight (8,650 lbs) of a one-third segment of the 8th stage disk, a maximum contact area of 11.65 ft^2, and an initial velocity of 383 miles per hour. The revised analysis showed that the existing structures will protect safety-related systems and components from high and low trajectory missiles.

In its safety evaluation [11], DECO concluded that stage 6 blades at normal overspeed conditions would not penetrate the LP turbines because (1) the weight of the stage 6 blade airfoils (11 lbs) is much less than the stage 8 airfoils (90 lbs), (2) the stage 6 blades would have to penetrate the thick outer cylinder in addition to the turbine casing, and (3) the stage 6 blades cannot pass axially beyond the pressure plates.

Findings

Based on its review, the staff has determined the following:

1. DECO has adequately addressed all seven contributing causes that have been identified;

2. The use of the pressure plates is acceptable based on industry experience, verifications of the design, and analyses by several of DECO's contractors;

3. DECO has adequately inspected the HP and LP rotors with NDE methods. The staff believes that remaining indications in the LP disk heads are insignificant;

4. DECO has adequately corrected the deformation in the LP rotors;

5. DECO has implemented acceptance criteria for turbine vibration that will protect the turbine-generator set from high vibration;

6. Under normal operating conditions, the fracture of disks for stages 1 through 6 blading is not likely, because NDE of the disks has shown satisfactory results. The fracture of disks for stage 7 and 8 blading is not likely because the blades on these disks were removed;

7. The stages 1 through 6 blades are not likely to penetrate the turbine because, (a) the weight of stage 1 through 6 blades is significantly

less than the weight of stage 8 blades, (b) the stage 1 through 6 blades are protected by outer cylinders in addition to the turbine casing, and (c) the stage 1 through 6 blades are stiffened with the tip of the blades being restrained by a shroud;

8. DECO has adequately modified, repaired, inspected, and tested HP and LP turbines to show that the turbines are not likely to generate missiles under normal operating conditions.

2.4 Chemistry Transient and Effect on Reactor Internals and Fuel

As a result of the December 25, 1993, catastrophic failure of the Fermi 2 turbine and subsequent rupturing of many tubes in the condenser, general service water from Lake Erie was dumped in large quantities to the condenser hotwell. The excess of water from the condenser was automatically routed to the CST degrading its water quality. This water was subsequently transferred to the reactor vessel by the reactor core isolation cooling system and the standby feedwater pumps. Injection of this unpurified water produced a very significant chemistry transient. Water conductivity rose from an initial <0.09 μS/cm to 182 μS/cm. Chloride concentration increased from < 1 part per billion (ppb) to 12.3 parts per million (ppm) and sulfate concentration from < 2 ppb to 10.8 ppm. Nitrate ion concentration reached 1.4 ppm. Water became alkaline with pH value rising from ~ 7.0 to 10.6. Also, oil leaking from the broken turbine oil system lines contaminated the condensate and feedwater systems.

The licensee's recovery operations consisted of a feed and bleed of the reactor pressure vessel using makeup from the condensate return tank (CRT), and hardpiping a sidestream demineralizer to the reactor water cleanup system (RWCU). This caused gradual improvement of the quality of water. In about 5 days the conductivity of water dropped to about 100 μS/cm and in the next 40 days it reached the value of 1-2 μS/cm. Similarly, chloride and sulfate concentrations were decreasing. In 14 days, chloride concentration dropped to about 8 ppm and sulfate to 4 ppm, and in the next 30 days chloride and sulfate concentrations were below 50 ppb. The total number of days water conductivity and chloride concentration remained outside of the technical specification (TS) limits for cold shutdown was 26 days for conductivity and 34 days for chloride concentration. The pH also decreased with time and in about 44 days reactor coolant water returned to a neutral pH (pH=7). During the accident, vessel cooldown did not begin until approximately 1 hour after the scram. A temperature of 350°F was reached in about 8 hours and remained there for the next 20 hours after which it was cooled to 150°F and remained at this value for the next 2½ days. It was then cooled to 100°F. The reactor coolant remained above 100°F for a little over 3½ days.

The chemistry transient also affected water purity in the spent fuel pool. However, the quality of water did not start to deteriorate until about 40 days after the reactor scram. This was due to a leak of contaminated water through a valve supplying makeup condensate water. Conductivity of the water increased sharply to 2-3 μS/cm with corresponding concentration increases for chloride and sulfate from the normal value of < 10 ppb for each to 100-200 ppb and 200-260 ppb, for chloride and sulfate concentrations, respectively.

Water with high coolant conductivity and high chloride and sulfate concentrations produces an envi nt conducive to degradation of materials in the plant. Data from materia testing indicates that both chloride and sulfate ions are contributors to stress corrosion cracking (SSC). The effect of high conductivity is to decrease the time for the initiation of cracking and its propagation. However, the high pH produced a less severe environment for corrosion; therefore, the deleterious effects of the transients were lessened. For this chemistry transient General Electric (GE) predicted that stress corrosion crack wetted by contaminated water would propagate at a rate of roughly twice that for normal BWR water.

In the recovery operation, the licensee was faced with two problems: to determine the potential corrosion damage produced by the exposure of plant components to abnormal water chemistry, and to develop a procedure for bringing and maintaining water chemistry within the TS limits after plant startup. A very detailed evaluation of these problems and recommendations for future actions were provided to the licensee by GE in reference [14]. The licensee adopted the recommendations and provided its assessment of the effects of the chemistry transient on reactor internals and fuel and corrective actions during a meeting with the staff on August 25, 1994, and in references [12 and 13].

2.4.1 Effect of Chemistry Transient on Corrosion of Plant Components

The activities conducted by the licensee in this area had for their objective: determine the magnitude and scope of any potentially negative effects caused by the chemistry transient, obtain baseline data for future comparison and identify any changes which may occur in the future, and assure that the components exposed to the contaminated water did not experience any significant corrosion damage requiring their repair/replacement. The licensee has inspected the following major components which were judged to be most susceptible to corrosion damage: reactor pressure vessel, control rod drives (CRD), core shroud, and shroud head bolts and fuel.

The reactor pressure vessel was examined for potential corrosion damage caused by ingress of contaminated water. The examination indicated the presence of two types of deposits. One consisted of a crusty reddish brown substance deposited on the stainless steel clad surface in the form of small islands, forming a band around the reactor vessel. The location and distribution of these corrosion deposits were consistent with the kind of corrosion activity associated with a water-air interface. The other corrosion product consisted of white to tan crusty "cornflake" type deposits. Although morphology of these two types of deposits was different, their chemical properties were remarkably similar, suggesting that they both were produced during the same event (i.e., lake water intrusion). The presence of aluminum suggested ingress from the CST. No significant pitting was observed beneath these deposits and examination of an unclad region at the feedwater nozzles did not suggest surface penetration.

In addition to the reactor vessel itself, the licensee performed an inspection of the following vessel internals: core spray piping, core shroud, steam dryer support brackets, reactor circulation inlet nozzle, "B" jet instrument nozzle, and

bottom head region. In these examinations the licensee could not find any damage which could be attributed to the ingress of contaminated water during the accident.

The components in the CRD judged to be most affected by the water chemistry transient are: collet retainer tube, index tube, and piston tube of the older style CRD assemblies. These components have been shown to be susceptible to intergranular attack, SCC and corrosion pitting. All these components were subjected to abnormal chemistry and temperatures of about 450°F for 1 hour and about 300°F for an additional 20 hours.

Six CRDs were inspected and all of them showed some signs of corrosion wear. The licensee concluded that the chemistry transient could have been one of the contributing factors. However, the observed wear was not significant enough to require any special repair efforts beyond the refurbishing of 20 CRDs which had previously been scheduled for RF04.

The shroud head bolts were identified as susceptible to corrosion because they were fabricated from Alloy 600/182 and there was a wetted crevice design along the weld heat-affected zone. Also, the bolts were exposed to medium mechanical stresses. A full length ultrasonic testing was performed on 48 bolts and 16 were found with rejectable indications at approximately 9.5 inches from the bottom of the bolt. This was a typical location for intergranular stress corrosion cracking found in other plants. Also, the number of the defective bolts was comparable to that in the other BWRs. The licensee concluded, therefore, that the chemistry transient did not cause any specific damage to the shroud head bolts. The defective bolts were replaced during RF04. The remaining bolts are scheduled for replacement during RF05. Fuel components from four bundles of irradiated fuel and scrapings from three bundles were inspected by GE in its laboratory to evaluate the impact of the chemistry transient on fuel. The components were first examined visually to characterize surface conditions of individual fuel rods. To confirm the results of visual examinations, optical metallography was also performed. These examinations have indicated that fuel materials have surface conditions characteristic for exposure to the normal BWR environment. The examination of the scrapings has indicated that the deposits were of a type commonly observed on the BWR fuel. It was concluded, therefore, that there were no unusual or abnormal conditions observed in the fuel that could be attributable to the intrusion of lake water, and future examinations of deposits at the next refueling outage would be only required if reactor water chemistry were to return outside of the specification limits (i.e., high conductivity, chlorides, significant pH variations, high metallic feedwater concentrations), or if another transient is experienced.

Since it was expected that the ingress of the lake water could induce microbiological influenced corrosion (MIC), analyses were made for microbiological organisms. Although such organisms were found, further examination has indicated that they appear to be slow growing and non-aggressive towards metal surfaces. All inspections have indicated that there was no MIC, and since the plant will be started in the relatively near future, normal operating temperatures and pressures will eradicate most of the

microbial activity. Some residual activity may remain which may manifest itself during the next outage, but it should present no problems during an outage of a normal duration. The licensee committed to be aware of it and take appropriate steps to monitor this microbiological activity.

The staff has reviewed the evaluations made by the licensee and by GE of the potential impact of the chemistry transient on corrosion susceptible components. The staff concurs with the licensee's conclusion that there were no significant corrosion degradations of the components which could be attributed to their exposure to abnormal water chemistry during the transient. However, even after establishing normal water chemistry in the plant, some crevices may still have high concentrations of the species which could cause corrosion in these areas. The licensee acknowledged the concern and has included appropriate monitoring actions in its startup testing program.

2.4.2 Establishing Normal Water Chemistry

After the turbine blade failure, water chemistry in the plant exhibited very significant departure from its specifications due to introduction of a large amount of lake water. Impurities considerably exceeded the values of Action Level 3, recommended by the Electric Power Research Institute (EPRI) in reference [15]. In order to resume normal plant operation, the licensee has to bring water chemistry to within TS limits and assure that during subsequent plant operation those limits are maintained. The licensee focused, therefore, on three areas: recovery of water chemistry after the transient, establishing water chemistry for plant startup, and maintenance of water chemistry during the startup operation.

Recovery Operation

The recovery of the reactor coolant chemistry started immediately after the chemistry transient. The licensee had to remove contaminated water and replace it with the clean water meeting chemistry specifications. Decontaminating water in the reactor vessel was achieved by feeding and bleeding with the uncontaminated water from the CRT and hardpiping a sidestream demineralizer to the RWCU system. Although in a relatively short time this action brought major variables (water conductivity, pH, and concentrations of chloride and sulfate) of the reactor coolant water within the specification limits for cold shutdown conditions, there were several abnormalities which had to be corrected before chemistry would be suitable for plant startup.

A major effort during the recovery operations was needed to remove contaminated water which flooded the plant. For that purpose the CST was used as a radwaste release tank and through it about 1.5 million gallons of low activity water were discharged into the lake. The residual heat removal system and recirculation piping were flushed with recovered reactor coolant and the RWCU system with its demineralizer was used to remove particulate and ionic species from the system. There was a temporary modification made to the CRD to supply clean water from the CRT. The rods were also exercised to reduce potential crud deposits. The feed and bleed operation took several months to complete cleaning the water in the torus. The other systems which

were affected by the chemistry transient included high pressure coolant injection, reactor core isolation cooling systems, standby feedwater system and the lines in the standby liquid control system. All of these were flushed and refilled with clean water.

There was a large oil leak into the plant from damaged turbine support systems. Some of the components were badly contaminated and had to be cleaned. The CST contained sludge deposits which had to be removed. The CST was cleaned with a hot water-soap solution and refilled with clean water. A similar cleaning process was used for the CRT. Most of the remaining oil was removed using several methods, such as a mixed bed demineralizer with carbon caps, cellulose fiber in the condensate filter demineralizer system and breakdown of organics by ultraviolet light.

The staff reviewed documentation of the licensee's actions taken in the recovery operation and finds that they led to an effective removal of the contaminants; thus bringing the plant to operating status.

Preparation of Plant for Startup

Before the plant can proceed with startup operations, the quality of water in all plant systems must meet the TS requirements. In order to achieve this goal, the licensee has developed a startup chemistry program. In developing this program the licensee used lessons learned at other nuclear power plants which experienced chemical and organic intrusions in their plants, the guidelines for water chemistry by the industry BWR Owners Group, and the recommendations provided by GE in reference [14]. The program provided assurance that the contaminated water was removed and all systems which were affected by the ingress of this water were cleaned and filled with uncontaminated water.

One of the important cleaning activities consisted of removing very thoroughly all remaining traces of oil from the system. This was crucial to maintaining water purity in the system because during the startup operation traces of oil would decompose, due to radiation and temperature effects, and create chloride, sulfate, and nitrate ions. The licensee used several methods for removing oil and other contaminants from the condensate, including replacing filter demineralizers bundles prior to condensate cycle operation, precote filter demineralizers with powdered resin and fiber overlay, and operating the condensate demineralizers in short cycles, until water meets acceptable quality limits prior to long cycle operation.

Plant Startup

Although during the recovery operation and the subsequent preparation for plant startup, most contaminants were removed and water chemistry complied with acceptable purity standards, the system may not be entirely free of chemical contaminants. It is possible, therefore, that sometime during plant restart operation, conditions may occur favoring hideout-return of many chemical species despite initial system good water quality. The licensee has implemented an acceptable chemistry monitoring program and plans to take appropriate actions in the event that water quality deteriorates.

The licensee committed to control water chemistry in the reactor vessel using chemistry procedure NPP CH1-01, "Chemistry Specifications" and the Chemistry Startup Plan. These documents were developed in accordance with the EPRI guidelines described in reference [15]. They list the requirements for controlling reactor water quality and action to be taken if this quality is not met. It is based on the methodology developed in the EPRI guidelines. This methodology recognizes three action levels to be taken by the operator, depending on the severity of water chemistry excursions. These levels are determined by the three most important chemistry parameters: conductivity and chloride and sulfate concentrations. Each action level corresponds to different values of these parameters. When Action Level 1 values were exceeded, the plant could still operate for 4 days; but within this time the operator is required to take corrective actions. However, when the Action Level 2 limits are exceeded, water chemistry parameters have to be reduced below Action Level 2 within 24 hours or an orderly plant shutdown should be initiated. Action Level 3 is the most severe and it indicates that conditions are reached when operation of the plant can cause component degradation in a short time. Once it is exceeded, immediate shutdown and reduction of water temperature to below 200°F is required.

The licensee has developed a procedure in which the operations corresponding to each step in the plant startup depended on the action levels reached by reactor water chemistry. In this way, maintenance of proper water chemistry is assured throughout startup of the plant.

The staff has reviewed, in detail, the licensee's water chemistry startup program and the commitments made to assure that the plant will have proper water chemistry during power operation. The program and all the activities described by the licensee were found to be acceptable because they assured that the plant water chemistry specifications will be in compliance with the acceptable industry standards.

2.5 Structural Engineering Restart Issues

The turbine failure on December 25, 1993, resulted in thrown blades and generated missiles, and the resulting vibration in the main turbine generator triggered seismic instruments [16]. Structural damages were assessed [17 and 18] and recommended repairs were reported by the licensee's staff [17 and 19] and its consultants [20]. The NRC staff has reviewed these reports and analyses that justified the integrity of damaged structural members and design calculations for the repairs, and held a telephone conference with the licensee's staff. The staff's review results and conclusions are stated below.

2.5.1 Turbine Building

A structural walkdown team was assembled to inspect all impacted areas and recommend repairs after the turbine incident. The scope of the walkdown included the turbine building, radwaste building, and reactor/auxiliary building. Structural elements were visually inspected for signs of damage or displacement. The elements examined included concrete slabs, walls, beams, columns, concrete foundations and pedestals, masonry walls, steel beams,

columns, bracings, stair stringers, doors and frames, penetrations, anchor bolts, and isolation joints.

Since the failure originated in the turbine, the items in the vicinity of the turbine, such as the turbine pedestal and the isolation gap between the pedestal and the turbine building were inspected with specific attention. The roof, siding, and supporting beams and columns of the turbine building and the overhead crane in the turbine building were also inspected in detail for structural and missile damages. A number of gouges (up to about 1/4 in. deep in the third floor concrete slab of the turbine building and 1/2 in. in the reheater concrete roof) caused by the missiles were found. Since no reinforcing bars were damaged, the licensee concluded that the overall integrity of these slabs was intact and the concrete was repaired. A small missile created a 1/2 in. by 1 in. perforation in the No. 18 gauge thick metal roof deck of the turbine building, and the hole has been repaired. The LP3 turbine blades resulted in missiles that penetrated the turbine casing and hit and damaged condenser tubing, a pipe support member and the grating at the platform nearby. The missile damage areas were found to be localized at the vicinity of impact, without significant effect to the overall structural integrity of components and structures, and they have been repaired. All the cracks, except one in the turbine building slab, were determined to be cosmetic in nature, and they were painted over. The non-cosmetic crack was repaired with structural grout.

The overhead crane east runway girder in the turbine building was hit by a suspected exciter missile and a dent was created in the web plate. There was no indication of any overall girder displacement. The girder section is built from a 3 in. thick and 24 in. wide top plate, a 2.5 in. thick and 20 in. wide bottom plate, and a 1 in. thick and 66.5 in. deep web. The dented area is about 11 in. in diameter and bowed in the direction perpendicular to the web plate with a depth of 3/4 in. No visual indication of any cracks on both the front and back surfaces was observed. The girder is 32 ft. long and simply supported at its ends. The dented area is located 4 ft. 10 in. away from one end and 1 ft. 2 in. above the bottom plate. In reference [21], the maximum shear force created by the crane at the section, where the dent is located, was calculated at 396 kips, and the available shear capacity, assuming that the dented area carried no load, was 1,357 kips. Since the static shear capacity of the girder was more than 3 times the static shear demand of the section at the dented area, it was concluded in reference [21] that the missile impact was absorbed by the localized plastic deformation in the web and the crane girder has sufficient capacity, as is. The staff agrees with this assessment because the dynamic shear demand would still be less than twice the static shear demand. The dynamic shear capacity is increased from its static shear capacity, and thus the margin of safety for shear failure for the dented crane girder is greater than 1.5. Moreover, the licensee stated that the two turbine cranes (each with 250 tons capacity) had lifted the 450-ton generator stator and traveled over the dented location. In addition to this heavy lift, many other heavy turbine components were moved over the dented location. The licensee's inspection following these heavy lifts had found the crane structure in satisfactory condition. The analytical results and the physical tests of lifting heavy loads have proved that the crane girder is adequate as is with the dent.

The exciter and its anchors and stool pieces were displaced from the concrete foundation. The exciter has been removed from the original foundation and relocated in the lower floor. The damage was local to the exciter anchor area, and the damaged area has been repaired. Thc generator was removed from its foundation and the whole supporting concrete structure including its anchorage were inspected and found to be in good condition.

The turbine was supported by steel box beams. The box beams are about 35 ft. long, 8 ft. wide, and 15 ft. deep. The side plates of the box beams have vertical stiffeners welded to the plate. There were cracks in the welds and the base metal of the side plates on beam Nos. 2, 3, 4, and 5. However, there was no distortion or warpage noted on these box beams. Ten samples were removed from cracked welds and sent for metallurgical analysis. The analysis results indicated that the cracking found in the box beams was caused by high stress-low cycle fatigue during the 1993 turbine failure. It was also found that the welds on the stiffeners had been improperly detailed, which resulted in stress concentration that contributed to the cracking. A new detail for the stiffeners was developed in reference [18] and the staff considers this new detail to be acceptable. Since all the cracks in the box beams have been repaired and the new detail of the stiffeners appears to be workable, the staff considers that the overall structural integrity of the box beams is not compromised.

The turbine is supported by a reinforced concrete pedestal, and the pedestal is isolated from the turbine building from the third floor down to the first floor level. The inspection of the turbine pedestal indicated no structural damage and that the isolation gap around the pedestal was intact with no anchorage or grout deterioration observed.

2.5.2 Radwaste Building

The radwaste building houses various tanks associated with the radwaste system. As a result of the basement flooding in the radwaste building after the turbine incident, three unanchored tanks in the basement were lifted off their foundations. They have been relocated on their foundations. Inspection of concrete walls, slabs, beams, columns, masonry walls, stairs, doors, penetrations, and anchor bolts in the radwaste building showed no sign of damage.

2.5.3 Reactor/Auxiliary Building

The reactor/auxiliary building is separated from the turbine building by a 4 in. gap. A walkdown was performed in the reactor/auxiliary building with special attention given to areas adjacent to the turbine building. No signs of damage were found. No signs of fresh cracks in concrete walls, columns, slabs, and masonry walls were observed. No signs of damage or distress in doors, penetrations, and anchor bolts were observed. All the architectural features in the control room, such as suspended ceilings and metal facade around control panels, were found to be sound and showed no signs of movement.

2.5.4 Seismic Instrumentation Data

Three seismic instruments are located in the reactor/auxiliary building, on the basement level, the second floor, and the fifth floor. The instruments are positioned to measure accelerations in the vertical, north/south, and east/west directions at each sensor. With these acceleration data, response spectra were generated. The seismic recorder located in the reactor/auxiliary basement indicated that the building foundation had experienced a safe shutdown earthquake exceedance. However, the seismic recorders on the second and fifth floors registered insignificant accelerations. An attempt was made in reference [16] to create artificial ground motion time histories that would match the response spectra generated from the recorded data. Only two instrumentation records contained enough significant data points for the exercise. They were the east/west and vertical directions data. The generated artificial time-histories are similar to shock incident time-histories, with short duration and high accelerations. Such a type of shock incident time-histories imparted low energy to the buildings as compared to the earthquake time-histories with similar peak ground accelerations. The fact that seismic records on the second and fifth floors registered insignificant accelerations is an indication that the duration of the shock waves generated by the turbine event was too short to excite the building structures in a significant way, and thus no damage to the building structures was observed.

2.5.5 Findings

The licensee has analyzed the seismic records, which were triggered by the vibration from the imbalance caused by the turbine accident, and concluded that the incident had generated waves through the foundations of building structures but imparted low energy to the structures. The licensee has performed walkdowns of the turbine building, radwaste building, and reactor/auxiliary building and concluded that the damage resulted from turbine missiles and turbine vibration imbalance to the supporting box beams. The damage has all been repaired, and the structural integrity of the buildings and structural members are not compromised. The staff agrees with the licensee's assessment on the cause of the damage and on the method of repairs. The staff considers that all the structural issues have been resolved for this restart action.

2.6 Resolution of Restart Action Plan Items

As stated previously, the Regional Administrator, in accordance with NRC Inspection Manual Chapter 0350, established a Restart Panel which developed a Restart Action Plan (RAP) to address the issues which required resolution prior to restart. Five of these items were assigned to the Office of Nuclear Reactor Regulation (NRR).

The first of these items was RAP item 11, to evaluate the licensee's corrective action plans for restoration of the turbine by operation with 7th and 8th stage blades removed and pressure plates installed on all three LP turbines. This item has been reviewed previously in section 2.1 of this safety evaluation and is considered resolved.

The second item assigned to NRR was to assist Region III in resolution of RAP item 13, to evaluate licensee repairs for structural damage including support beams, bearing boats, and turbine cradle as well as floors and walls of the turbine and other buildings. This item was reviewed in section 2.5 of this report and is considered resolved.

The third item assigned to NRR for resolution is RAP item 17, to evaluate the chemistry excursion effects on reactor internals. This item was reviewed in section 2.4 of this report and is considered resolved.

The fourth item assigned to NRR for resolution is RAP item 24, to review the licensee's determination regarding Inservice Testing (IST) Program applicability for testing newly installed check valves in the floor drain system between the radwaste building and the reactor emergency core cooling system (ECCS) corner rooms.

During the event, a concern was raised that the water/oil mixture which had flooded the radwaste building could potentially drain to the ECCS corner rooms (which are at a lower elevation) via gravity drain through the connecting floor drain system. This was prevented by check valves in the drain lines which are classified as non-Q, non-American Society for Mechanical Engineers (ASME) Code (Code) class valves (based on the current classification of the portion of piping in which they are installed). These valves were not previously included in the IST program or any other periodic testing program to ensure that the valves would open to drain the room and close to prevent radioactive backleakage into the ECCS corner rooms.

The licensee has modified the drain lines to add two additional redundant check valves and a normally open manual isolation valve to each line and has included testing features which will enable backseating of the check valves. The licensee provided the staff a copy of the test procedure for testing of these valves. The newly installed ECCS drain line check valves will be functionally tested each refueling outage per an existing "augmented" testing program. This program supplements the IST program developed and implemented in accordance with 10 CFR 50.55a for certain valves not within the scope of 10 CFR 50.55a.

Because the valves are designated as non-Q and are not classified as ASME Code Class 1, 2, or 3, they are outside the scope of 10 CFR 50.55a; however, periodic testing is an element of the continued assurance of the functionality of these valves in accordance with the quality assurance requirements of 10 CFR Part 50, Appendix B. The "augmented" testing program is subject to quality assurance requirements of Appendix B and contains acceptance criteria. The test frequency, once per refueling outage, is consistent with the requirements for valves subject to IST requirements of 10 CFR 50.55a.

The licensee's proposal to perform periodic testing of the ECCS corner room drain valves is acceptable based on (1) the valve not being within the scope of 10 CFR 50.55a, (2) the quality assurance requirements imposed on the testing, and (3) the method and frequency of testing being consistent with check valves subject to IST. Implementation of the testing is subject to NRC inspection.

The fifth item assigned to NRR for resolution is RAP item 25, the acceptability of a completed proof test on four sections of ductwork on the control complex heating, ventilation, and air conditioning (CCHVAC) system that would see the highest negative pressure during worst case system operation. The licensee documented the results of the test by letter dated November 3, 1994. This test was conducted on October 10, 1994, in accordance with ANSI/ASME N509-1980 paragraph 5.10.8.2 (fan pressure test). The test pressure was held for at least 5 minutes and no plastic deformation of duct corner joints in seams was observed. Minor in-leakage was detected at damper shafts and at gasketed access panels in the north and south emergency intakes in one of the four sections. This minor in-leakage was within the allowable 1% leakage for Class II ducts as defined in Appendix B of ANSI/ASME N509. Further, any in-leakage from the emergency intakes would be subject to the same degree of filtration as the potentially contaminated outside air drawn into the intakes. The licensee has stated that the minor in-leakage will not impact flowrates, filtration efficiency, or the bypass leakage path used to determine the Iodine Protection Factor (IPF) for the main control room. The IPF is used to calculate the post-accident control room operator dose. Thus, calculated operator doses would not be affected by the minor in-leakage. Based on the results of the test, as documented in the licensee's November 3, 1994, letter, the staff considers this item to be resolved.

3.0 CONCLUSIONS

The staff has determined that the licensee has adequately addressed the contributing root causes that have been identified for the December 25, 1993, turbine failure event. The licensee has adequately modified, repaired, inspected and tested the high and low pressure turbines to show that the likelihood of turbine missile generation is remote. The licensee has developed an adequate startup testing program to monitor turbine vibration and institute appropriate corrective actions during the return to power.

The staff has also determined that the licensee has adequately inspected and analyzed the effects of the chemistry transient on reactor internals and fuel. The licensee's program and corrective actions to restore reactor water chemistry following the December 25, 1993, turbine failure event are acceptable. The licensee has also developed an acceptable startup testing program to monitor reactor chemistry during the return to power operation. This program provides assurance that acceptable reactor water chemistry will be maintained.

The licensee has adequately analyzed and repaired the structural damage associated with the turbine failure event. The staff agrees with the licensee's assessment on the cause of the damage and on the method of repairs.

The licensee has completed modifications to address staff concerns related to flooding of ECCS corner rooms. The licensee has further developed an acceptable testing program to provide continued assurance of the integrity of the drain line check valves.

The licensee has conducted an acceptable proof test of portions of the CCHVAC system in accordance with ANSI/ASME N509-1980.

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4.0 REFERENCES

1. Detroit Edison Company, "Fermi 2 Main Turbine Generator December 25, 1993 Forced Outage Root Cause Analysis Report, "TMTB 0010-0801.21, July 1994. [Proprietary information. Not publicly available.]

2. Failure Prevention International, Inc, "Interim Status Report Independent Root Cause Analysis Assessment of the Detroit Edison Fermi 2 Turbine-Generator Event on December 25, 1993," San Clemente, California, July 26, 1994. [Proprietary information. Not publicly available.]

3. GEC Alsthom, "Fermi 2 Turbine Generator Incident 25th December 1993 Root Cause Investigation Conclusions Based on Information Available Up to 30th June 1994," Great Britain, June 1994. [Proprietary information. Not publicly available.]

4. Detroit Edison Company, "Executive Summary Root Cause Analyses of Fermi 2 Main Turbine Generator Event," August 27, 1994.

5. Stress Technology Incorporated, "LP L-0 Rotating Stage Failure Investigation on LP3 rotor at Fermi 2," Technical Report PA 942, Rochester, New York, September 1994. [Proprietary information. Not publicly available.]

6. J. E. Schaefer, "Metallurgical Analysis of Fermi 2 LP3 Eighth Stage Turbine Blading," Detroit Edison Company, Report No. 94V70-13, June 20, 1994. [Proprietary information. Not publicly available.]

7. Ratliff, P. R., Westinghouse, letter to L. Fron, Detroit Edison, subject: Pressure Plating Evaluation Report, July 13, 1994. [Proprietary information. Not publicly available.]

8. Summy, J. S., FPI, letter to L. Fron, Detroit Edison, subject: FPI Review of Pressure Plate Use on Fermi-2, June 15, 1994.

9. Hardy, C.D., Heat Exchanger Systems Inc., letter to M. Deora, Detroit Edison, subject: Condenser Vibration/Performance Analysis Fermi Unit 2, July 21, 1994.

10. Detroit Edison Company, "Turbine Generated Missile Protection of Reactor/Auxiliary Buildings and RHR Complex," Design Calculation number DC-5144, September 1994.

11. Detroit Edison Company, "Turbine Missile Accident Safety Evaluation, SE-94-0073, Rev.1," October 1994.

12. Gipson, D. R., Detroit Edison, letter to USNRC, subject: Response to Confirmatory Action Letter on December 25, 1994 Turbine Event, August 24, 1994.

13. Gipson, D. R., Detroit Edison, letter to USNRC, subject: Supplementary Response to Confirmatory Action Letter on December 25, 1995, Turbine Event, October 13, 1994.

14. General Electric Company, "Enrico Fermi 2 Materials and Fuels Evaluation - Final Report, Vol 1 and 2," Report NEDC-3232(?), September 1994. [Proprietary information. Not publicly available.]

15. Electric Power Research Institute (EPRI), "BWR Water Chemistry Guidelines-1993 Revision. Normal and Hydrogen Water Chemistry," Final Report TR-103515, February 1994.

16. Hopper and Associates, Engineers, "Fermi 2 Turbine Failure - Post Event Earthquake Instrumentation Data Evaluation," August 5, 1994.

17. Detroit Edison Company, "Structural Walkdown Final Report," August 8, 1994.

18. Detroit Edison Company, "Turbine Bearing Beam Repairs", TSR-26565, August 25, 1994.

19. Detroit Edison Company, "Metallurgical Evaluation of Bearing Pedestal Box Beam Weld Cracking, Fermi 2," June 21, 1994.

20. Sargent & Lundy, "Assessment of Turbine Bearing Beam Cracking", SLAM-029, May 10, 1994.

21. Detroit Edison Company, "Verification of Turbine East Side Overhead Crane Girder 2", DC-5882, January 21, 1994.