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In the Matter of
Metropolitan Edison Company, Et Al.
(Three Mile Island Nuclear Station, Unit No. 1)
Docket No. 50-289-OLA and ASLBP 83-491-04-OLA
(Steam Generator Repair)

Dear Administrative Judges:

For the information of the Licensing Board and the parties, I am enclosing a report prepared by the Subcommittee on Steam Generator Repair of the TMI-1 General Office Review Board (GORB). The report deals with the repair of the steam generator tubes.

Sincerely,

Bruce W. Churchill

BWC:smm
Enclosure
cc: Service List

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TMI-1 GORB SUBCOMMITTEE ON STEAM GENERATOR REPAIR

REPORT TO THE TMI-1 GENERAL OFFICE REVIEW BOARD

13 June, 1984

T. L. Gerber, Member

D. T. Leighton, Member

R. N. Whitesel, Member

W. W. Lowe,
Subcommittee Chairman

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I. BACKGROUND

In late November 1981 following hot functional tests in August and September, a large number of tubes in both steam generators of TMI, Unit 1 were found to be leaking. Subsequent eddy current measurements indicated that several thousand of the 15,531 tubes in each generator were cracked circumferentially from the inside. Most of the cracks were near the top of the tubes where the tubes are in the 24" thick upper tube sheet. In the Fall of 1982 extensive additional cracking was discovered at the top end of the tubes where they extend a fraction of an inch above the tube sheet. Destructive examination showed tube cracking to be intergranular. Sulfur compounds in significant amounts were found both on fracture surfaces and on the inside of tubes and other primary system interior surfaces.

Ultimately about 1200 tubes with greater than 40% thru-wall indications below a level 8" above the underside of the upper tube sheet were plugged. All tubes not plugged were explosively expanded to seal them against the tube sheet. The specification for the seal requires that it be six inches or more in length and below all known defect indications as found by eddy current tests prior to explosive expansion. Test data were taken and analyses were done which show that such a seal provides leak tightness and structural strength equivalent to the original joint.

Following the discovery of cracking, GPUN initiated a comprehensive investigation to establish the cause, to measure the extent and nature of damage to the steam generators and other equipment, to investigate methods for repair and to define conditions for the repair, recertification, restart and operation of the unit. GPUN has issued reports on all of these subjects.

The Subcommittee on Steam Generator Repair of the TMI-1 General Office Review Board (GORB) was appointed by the GORB Chairman at GORB Meeting No. 48 on 22 April 1982. The Subcommittee was asked to draft an opinion for the GORB's consideration concerning the safety of the restart and operation of TMI, Unit 1 as it might be affected by the repair of the steam generators and by their as-repaired condition.

The Subcommittee has met about 30 times since April 1982 for a total of more than 200 hours. It has had more than 50 hours of presentation by GPU Nuclear Personnel on matters relating to its assignment and it has had continuing access to pertinent documents prepared by GPUN and its contractors.

From time to time the Subcommittee has made written requests for information. Further, in its meetings with GPUN representatives, it has questioned and commented on the developing state of knowledge about the steam generators and upon actions proposed or taken by GPUN.

At TMI-1 GORB meeting 50 on 11 August 1982 the Subcommittee proposed a GORB recommendation concerning control of plant chemistry. This recommendation, as subsequently revised, was approved by the GORB in telephone meeting 50A and issued as GORB Recommendation No. TMI-1-50-1. The Subcommittee considers the GORB recommendation and the associated background statement to be a fundamental representation of its views and incorporates them by reference as part of this report. The GORB received an official response to the recommendation at its 14 December 1983 meeting.

On 8 September 1982 the Subcommittee formally concurred with the GPUN finding that plans for steam generator repair gave sufficient assurance that the repair process, in itself, was safe. On 10 August 1983 the Subcommittee issued an interim report to the GORB concluding that subject to the resolution of several matters, the safety of TMI-1 restart and operation would not be adversely affected by the repaired steam generators. On 22 August 1983 the Committee forwarded an opinion to the GORB Chairman that the full pressure hot functional test of the generators could be conducted with minimal risk to the public.

The Subcommittee's conclusion concerning the safety of operation with repaired steam generators is stated in Section II, along with the provisions upon which it is based.

Subcommittee recommendations appear as indented numbered items at the end of Sections VII, VIII and IX. Consideration of these recommendations is not viewed by the Subcommittee as being a prerequisite for power operation.

II. CONCLUSION

The Subcommittee concludes that TMI, Unit I can be safely operated with the repaired steam generators provided:

(1) on-site capability is established and implemented for measuring with a short turn-around time reduced sulfur compounds in primary water at and below concentration limits considered to be low enough to prevent damage (Section IX). Such capability should be implemented as soon as feasible, but in any event before the primary system is exposed to air after power operation;

(2) prior to power operation, operators (a) are trained to understand all plant instruments and symptoms which could be used to indicate subcooling margin and loss of subcooling, (b) are required to determine subcooling margin using at least two different instrument sets when controlling plant depressurization and cooldown following a tube break and (c) are trained to understand what would happen in the plant and what they would observe if the error in a subcooling margin measurement is larger than actual subcooling margin in the plant and they were using such a measurement to control subcooling (Section VIII (2));

(3) Prior to power operation, GPUN complete and evaluate an additional steam generator leakrate test to be performed by plant operators, as presently planned, utilizing injection of krypton into the primary system.

(4) results from additional hot functional tests, start-up tests and steam generator inspections planned 90 to 120 days after power operation do not show signs of significant tube degradation (Section VII).

III. CAUSE OF STEAM GENERATOR DAMAGE

A program to investigate the cause of extensive cracking in the Inconel 600 tubes of the TMI, Unit 1 steam generators was undertaken by GPUN and their contractors soon after discovery of primary to secondary leaks in November 1981. Major elements of this program included (1) review of the fabrication history; (2) in situ and laboratory examination of tubes and tube cracks; (3) review of plant water chemistry and operating history; (4) tube stress analysis, and (5) development of a failure scenario. In addition, an extensive corrosion test program was undertaken to investigate the cause of cracking and the performance of repaired tubes with and without chemical cleaning.

The Subcommittee is satisfied that the cause of cracking has been thoroughly investigated, and that the most likely failure scenario has been defined. This scenario indicates the cause of tube cracking was the presence of reduced sulfur compounds in the primary water which created an environment conducive to intergranular stress corrosion cracking of tube material at the static air-water interface in the upper part of the steam generators when they were partially drained during shutdown following hot functional testing in August and September 1981. The tubes were sensitized during heat treatment of the steam generators. The majority of cracks occurred where the tube material tended to have locked stresses in the upper seal weld region and the roll transition zone.

During the course of the Subcommittee's review, a number of questions related to the cause of cracking were posed. The majority of these questions were concerned with understanding the cause of cracking in sufficient detail so that potentially related problems could be identified, and the safety of future operation could be assessed. A related objective in some of the Subcommittee's questions was to understand how to reduce the chance of future damage due to inadequate chemistry control.

There is strong circumstantial evidence to support the failure scenario proposed by GPUN. Laboratory simulation of a range of conditions shows stress corrosion cracking of the sensitized Inconel 600 tube material will occur at relatively low temperatures when it is highly stressed and is

submerged in aerated water containing reduced sulfur compounds (e.g., thiosulfate ion) at concentrations as low as one ppm. There is a high probability sodium thiosulfate was inadvertently introduced into primary water from the borated water storage tank the contents of which had been contaminated with thiosulfate bearing water from the containment building spray system.

IV. INSPECTION FOR STEAM GENERATOR DEFECTS, REPAIR OF DEFECTS, AND INSPECTION OF REPAIRS

As they were being developed and implemented, the Subcommittee reviewed the programs to identify and characterize steam generator tube defects, to repair the tubes and to inspect the repairs. Based on its review, the Subcommittee concludes that the inspection, repair, and reinspection techniques developed and implemented by GPUN and its contractors and subcontractors have been thorough and have properly utilized state of the art techniques available.

V. DISTRIBUTION OF SULFUR

Circumstantial evidence indicates sulfur-induced intergranular stress corrosion cracking damaged steam generator tubes, pilot operated relief valves, gaseous waste piping, and spent fuel pool cooling pipe. Sulfur compounds were found in the cracks as well as inside the pressurizer and at other locations in the primary system. From all this it is inferred that sulfur compounds were present throughout the primary system and in some connected systems.

The spent fuel pool cooling pipe was repaired several years ago, and no further deterioration has been detected. The TMI-1 pilot operated relief valve (PORV) was replaced with a spare valve. The corroded PORV was cleaned, repaired, and subsequently reinstalled. In early 1984, the valve was removed, inspected, and found to be in good condition. The gaseous waste piping has been repaired. The steam generator tubes have been repaired or plugged as required.

An extensive examination by GPUN was made to determine whether damage other than that identified above had occurred in the primary system or in systems connected to it. These examinations have not revealed any additional damage related to sulfur induced corrosion.

VI. CHEMICAL CLEANING TO REMOVE SULFUR

A hydrogen peroxide chemical cleaning process has been carried out to remove sulfur from the primary system. Prior to chemical cleaning, internal surfaces of the pressurizer were cleaned with high pressure water jets.

The chemical cleaning process was designed to convert residual reduced sulfur species in surface deposits to soluble sulfates, and to remove them from primary water by ion exchange. Tests on TMI-1 steam generator tube samples by Battelle Columbus Laboratories indicated that reductions of 50 to 80 percent of the sulfur species could be achieved. No harmful effects were identified by the tests of the cleaning process.

While the Subcommittee recognized that there were uncertainties as to need and effectiveness, it believed it prudent to proceed with the cleaning. It reviewed the plans and specifications for cleaning and found them adequate.

VII. EVALUATION OF THE INTEGRITY OF REPAIRED STEAM GENERATORS

GPUN has carried out an extensive program to establish the integrity of the repaired steam generators and to demonstrate that they can be operated safely. The program has four essential objectives. The first is to qualify the repaired areas to original design criteria. These areas include the explosively expanded tube to tube sheet joint, the plugged tubes and the upper ends of the tubes which were repaired by machining and cleaning. The second objective is to verify that unrepaired sections of steam generator tubes below the expanded joint in the upper tube sheet do not now contain cracks which could rupture in normal operation or design basis transients or accidents. The third

objective is to demonstrate that the corrosion mechanism which caused the damage has been arrested and will not reactivate. The fourth is to demonstrate that, if tubes deteriorate from intergranular stress corrosion cracking in the future, leakage through them will be detected in sufficient time to shut the plant down before a tube breaks.

The first two objectives of this program have been achieved utilizing repair mock-ups, detailed analyses of repaired and unrepaired portions of the steam generators, laboratory tests, extensive steam generator inspections before and after repair and comprehensive hot functional tests.

The third objective, demonstrating that the corrosion mechanism has been arrested and will not reactivate, has been addressed in several ways. Laboratory tests and chemical thermodynamic analysis of sulfur compounds have been made to establish specifications for primary coolant chemistry so that conditions known to cause damage will be avoided under operating and shutdown modes. Hot functional tests of the repaired and cleaned steam generators have been and will be conducted to detect tube deterioration by measuring primary to secondary leak rate. Long-term corrosion tests are being carried out which simulate plant operating cycles before they are experienced in the plant. Test results to date show no evidence that cracking has continued or that it will occur under conditions specified for future operation.

To serve the fourth objective, GPUN has established a primary to secondary leak rate administrative limit of a nominal 6 gallons per hour (GPH) above a baseline value (currently one GPH) during power operation as determined by noble gas radioactivity in the primary coolant compared to that in condenser off gas. If the leak rate exceeds the nominal value during steady state operation, the plant will be shut down and the steam generators inspected. After each plant cooldown, leak rate measurements made during the cooldown period will be evaluated before power operation is resumed. Also GPUN is required by Technical Specifications to bring the plant to cold shutdown if the primary system unidentified leak rate exceeds 1 gallon per minute (60 GPH).

The Subcommittee believes that proposed leak rate limits and plans for evaluating cooldown data are appropriate and have a high probability of identifying significantly degraded tubes so that the unit will be shut down before a tube break due to intergranular stress corrosion cracking could occur.

Based on its review of the information and documentation in support of the four objectives, the Subcommittee recommends that:

(1) GPUN document the updated description given orally to the Subcommittee about the logic, analyses, and leak rate measurements which provide the bases for concluding that leaks from significantly degraded tubes will most likely be detected before one of them breaks. Clarification is needed because statements in early GPUN reports and quantitative analyses, when viewed individually, imply conclusions which are more definitive than can be supported by current state of the art analyses. Such clarification is needed so actions taken to assure safe operation (including primary to secondary leak rate measurements) can be kept in proper perspective.

VIII. ANALYSIS OF PLANT RESPONSE TO STEAM GENERATOR TUBE LEAKS/RUPTURES AND ADEQUACY OF OPERATING AND EMERGENCY PROCEDURES AND TRAINING TO CONTROL TUBE LEAKS/RUPTURES.

The Subcommittee has recognized from the outset, as has the GPUN staff, that tube ruptures or large leaks may occur due to future degradations or to existing conditions not now recognized. Therefore, the acceptability of future operation of these or any other nuclear steam generators must rely on confidence that operators will be able to shut the plant down before leakage creates a hazard to people or damage to the plant. This confidence has to be founded on a judgment of how tubes can break, on analyses of how the plant responds to tube breaks, on an ability to detect leaks which warn of incipient breaks and, most importantly, on the adequacy of operating and abnormal transient procedures and operator skill and training. Consequently the Subcommittee has reviewed these matters in detail.

Although GPUN is continuing to refine their analyses of plant response to abnormal transients such as postulated main steam line breaks and the related effects on steam generator tubes, the Subcommittee is satisfied that sufficient data has been developed through analyses and simulator drills to validate the approach used to control tube leaks (less than 50 gpm) and tube ruptures (50 gpm or greater) as specified in the new TMI-1 Abnormal Transient Procedures (ATPs). Based on its review and provided the training cited in paragraph (2) of Section II is completed, the Subcommittee considers that the present state of the procedures and operator training is sufficient to provide a high degree of assurance that the operators can safely handle tube leaks and ruptures should they occur, including leak rates from multiple tube ruptures which exceed the design basis by a significant amount.

The Subcommittee recommends that the following points be considered for procedure revisions, operator training, plant testing and/or analyses:

(1) An independent verification should be made of the error analysis which supports selecting the subcooled margin limit applicable to reactor coolant pump trip following a steam generator tube break. The verification should be equivalent to that required by ANSI Standards for design verification. The analysis and the verification should be subject to an interdisciplinary technical review by senior engineers who understand error analysis and primary system response to tube breaks and other loss of coolant accidents.

(2) For tube rupture transients,the Subcommittee concurs with the desirability of reducing indicated subcooling to 25°F (provided this value is verified as noted above) or to emergency RCP NPSH limits (whichever is more limiting). However, the possibility exists that an instrument string which measures subcooling margin could read erroneously high by more than 25°F. If that were to happen,it is important that the operator recognize that the instrument is in error, since once actual saturation has been reached the instrument reading will "hang up" at the value of error (higher than 25°F in this postulated case) while the operator continues to reduce

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pressure. The instrument will not indicate lower saturation margin until superheating from uncovered fuel commences. Since there are several independent instrument strings which can be used to measure subcooling, the Subcommittee does not consider it credible— that they would all read erroneously high by more than 25°F at the same time, provided calibration procedures and equipment preclude a common error in all the instrument strings. Therefore, the operator should be able to avoid reaching saturation conditions without knowing it. However, it is important that all operators understand the symptom (described above) which would be observed in this case and that they understand which other plant symptoms would indicate saturation had occurred (i.e., changes in pressurizer level, pump current, etc.). The Subcommittee recommends these matters be addressed in the training discussed in Section II (2).

(3) In the event of a tube rupture, operating the reactor coolant pumps as long as feasible (without incurring real trouble if they are subsequently shut off) can reduce total leakage through the break. Therefore, if the results of ongoing analyses show that the time limits for reactor coolant pump trip can be extended, the current limits should be reconsidered.

(4) The new fuel pin in compression limits released by B&W should be incorporated into TMI-1 operating procedures as soon as practicable. These limits will apply to normal heatup and cooldown and tube leak (less than 50 gpm) transients. Comparison of these limits with the cooldown data in TDR 488 shows that the new fuel pin in compression limits will allow much greater depressurization of the RCS before a cooldown results in high tube tensile stress due to tube to shell differential temperature. Since any tube cracks can be expected to open wider as the tube to shell differential temperature increases during cooldown, it is important that the tube leak procedure (ATP 1210-5) and/or the training program stress that in responding to a tube leak (less than 50 gpm) priority be given to minimizing

primary pressure within allowable limits before the cooldown results in high tube to shell differential temperature. This will reduce the total leakage during the cooldown. Further, if the leak then develops into a rupture (greater than 50 gpm) as the tube tensile stress builds up (as happened at Rancho Seco in May 1981) the resulting leak rate will be less, and the time needed to reduce the RCS pressure to RCP emergency NPSH limits allowed under tube rupture conditions will be less. Also, the RCS pressure is more likely to be below the secondary side safety valve lift pressure before the rupture occurs.

(5) Use of the new fuel pin in compression limits would permit plant testing over a wider range of temperature to verify the RCP emergency NPSH limits applicable to tube rupture and LOCA events. Such tests should be considered.

(6) Since the procedure for a tube leak (less than 50 gpm) requires that fuel pin in compression limits and normal RCP NPSH limits apply, these requirements should appear next to each other in the procedure and both should refer to the same graph, probably Figure 1 and 1A in OP 1102-11 (Plant Cooldown). There would then be no need for fuel pin compression limits in ATP 1210-10.

(7) The list of questions in the form for the Reactor Trip Report attached to ATP 1210-1 should include: "Were fuel pin in compression limits violated?" since, if they were, the data would normally be evaluated by B&W before restart.

(8) Guidance should be given in the ATPs and OP 1102-11 as to what actions are required if the cooldown rate exceeds 100°F/hour for limited periods.

(9) The Abnormal Transient Procedures should be clear and coherent to reduce chances of mistakes in handling tube breaks. These ten procedures could be improved if they were all made consistent in the following respects:

a. Consistently refer to ATP 1210-10 whenever a requirement from that procedure is required to be invoked to

carry out a step in the other nine procedures. At present some steps in some of the ATPs do this, but others do not.

b. Whenever "subcooled margin" is intended to mean "25°F subcooled margin", so state. At present this is done sporadically throughout the ATPs.

c. Use a consistent paragraph numbering system.

IX. CONTROL OF FLUID CHEMISTRY AND PLANT CHEMICALS

Damage to the steam generator tubes, the PORV, the fuel pool cooling system, and the waste gas system occurred because methods then in use for controlling water chemistry and the ingress of deleterious chemicals were inadequate, as was the understanding of potentially damaging situations and how they could occur. Since then GPUN has implemented extensive measures to improve the control of plant chemistry.

Provided the capability for measuring reduced sulfur compounds in primary water as described in Section II, paragraph (1) is established, the Subcommittee considers current GPUN capability for control of fluid chemistry and plant chemicals, if assiduously applied, is sufficient to keep the related risk from steam generator malfunctions at an acceptably low level during start-up and power operation. However, the Subcommittee recommends that:

(1) Concentration limits for reduced sulfur compounds and total sulfur in secondary water be established for operating and shutdown modes as soon as feasible at levels low enough to prevent damage. This is not a prerequisite for power operation.

(2) That continuous on-line monitoring of important chemistry parameters in primary water be established to the extent practical so that short-term variations in parameters can be detected, recorded, and, if they approach or exceed limits, alarmed. This is not a prerequisite for power operation.

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
	)	
METROPOLITAN EDISON COMPANY, ET AL.	)	Docket No. 50-289-OLA
	)	ASLBP 83-491-04-OLA
(Three Mile Island Nuclear Station, Unit No. 1)	)	(Steam Generator Repair)

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