GPU Nuclear

TECHNICAL DATA REPORT

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ABSTRACT: As a result of the presence of intergranualr attack and stress corrosion cracking on the TMI-1 OTSG tubes, GPUN initiated an extensive investigation to determine if similar evidence of stress corrosion cracking conditions exist in the Reactor Coolant System. The investigation started with the development of an Inspection and Test Plan which was based on an analysis of existing systems, components, and parts and their known susceptibility to intergranular attack in a solution containing sulfur species. The Inspection & Test Plan included a series of functional test nondestructive examinations and destructive metallurgical examinations which were designed to determine the presence of intergranular attack and stress corrosion cracking.

The results of the 22 Inspections and Tests which involved over a thousand select components, indicated that there was no evidence of a problem similar to that seen on the OTSG tubes. The functional tests all indicated that the tested assemblies were operational. The destructive examinations revealed that even on a microscopic level, no evidence of intergranular attack could be found. Therefore we conclude that based on this Inspection & Test Plan, the materials in the Reactor Coolant System are re-certified for continued safe operation.

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APPENDICES

I. INTRODUCTION

This report discusses the objectives and presents the results of the GPUN materials investigation and test program for the TMI-1 Reactor Coolant System and the Primary Side Auxiliary System. The objective was to evaluate the suitability of the systems' materials and components for safe continual operation of Unit 1. To accomplish this, a test program was developed to determine whether any material damage occurred due to potentially aggressive environmental conditions known present in portions of the primary coolant loop. It was previously concluded by the Failure Analysis Task Group (Task 1) that the primary system environment had contributed to sulfur induced integranular stress corrosion cracking of Inconel 600 tubes in both of the TMI-1 steam generators.

The Primary System Review Task Group, identified as Task 7 of the Once Through Steam Generator Task Organization, was organized under the direction of N. C. Kazanas and included individuals from a variety of organizations within GPUN. Key individuals in this group are shown in Appendix A. A similar primary system review task group was organized at Babcock & Wilcox under the coordination of H. W. Behnke. This group worked under the project direction of N. C. Kazanas and individuals that assisted this effort are shown in Appendix B.

The published program plan produced by the joint efforts of Task 7 is described in a document entitled:

- Task 7 Reactor Coolant System Inspections and Requalifications (BAW 1727) dated 4/16/82

The Program Plan produced, included the development of a series of functional tests and inspections which were designed to investigate specific material, environment, and stress combinations expected to be most susceptible when subjected to the same conditions which produced intergranual stress cracking for the steam generator tubes.

If negative results were encountered, then Task 7 was prepared to further extend its inspection and test programs to include other material/environment and stress combinations that were experiencing less severe exposure in an effort to determine the full extent of damage.

Additionally, Task 7 decided to inspect some generic B&W problems that presented themselves as available for inspection; however, Task 7's primary interest was to evaluate potential damage resulting from a sulfur induced intergranular attack. It was therefore necessary to be prepared to react to negative results with an evaluation that would immediately pinpoint the root cause of the problem and determine if it was other than a sulfur induced intergranular attack. The generic problems being inspected included:

1. Core Barrel Bolt Failure Problems
2. Hold-down Spring Problems
3. HPI Thermal Sleeves

The Inspection Plan included material/stress combinations within the three differing environmental conditions described by BAW 1727 as follows:

1. The primary coolant - gas interface areas. This is where the known attack occurred in the OTSG during the cold shutdown condition.
2. Those areas that are wetted during hot, pressurized operations and dry when the plant is cold, depressurized and shutdown.
3. The areas covered by primary coolant.

Each inspection was evaluated by one of the following methods and the results were recorded and collected in Appendix C:

1. Ultrasonic Examination
2. Visual Examination
3. Eddy Current Examination
4. Dye Penetrant Examination
5. Destructive Metallurgical Examination

6. Radiographic Examination

7. Functional Check Examination

8. Wipe (surface samples)

Implementation of each individual test/inspection was performed under the control of TMI Site Administrative Procedures including reviews prior to implementation for safety precautions, prerequisites, ALARA, and quality considerations.

II. STATEMENT OF THE PROGRAM

Background

The failure analysis of the corrosion attack of Inconel 600 revealed areas of intergranular stress corrosion cracking initiated from the primary side and localized areas of intergranular corrosion (IGA) on the secondary side. The more severe attack has been observed on the primary side of the steam generator tubes. Analysis of the primary side intergranular defects has identified the presence of a sulfur contaminant. The circumferential orientation of the defects suggest an axial stress is also associated with the failure mechanism. The defects are located in the OTSG upper tube sheet region where a coolant-gas interface exists.

The contaminants may have been concentrated by the alternating wetting and evaporation at these interfaces which created a favorable environment for intergranular corrosion attack. There were indications that this mechanism may be operating at low temperature and may be fast acting.

Because metallurgical failure analysis indicated that the intergranular attack initiated from the primary side to the secondary side and damaged thousands of the 31,000 steam generator tubes, GPU Nuclear decided to develop and conduct a full scale Inspection and Test Program of components in the primary system. Of particular concern in the program were material combinations which had historically shown a susceptibility toward sensitization and stress corrosion cracking. The combinations that received special attention included materials under high stress or materials that had been sensitized thru welding or having undergone post-weld heat treatment.

Organization

Task 7 to the OTSG Tasks Organization was chartered as the Primary System Review Task Group. The purpose was to develop an inspection program and then perform inspections and tests on components in the reactor coolant system, evaluate the results, and determine if additional testing was required. If results revealed problems similar to the intergranular corrosion cracking which had been observed in the steam generators, recommendations for additional testing would follow. Based on the additional testing, a repair and/or replacement program to requalify the unit for safe continued operations would have been pursued. This task was headed up by GPUN with support from Babcock and Wilcox. After the responsibility for each organization was defined, planning for reaching these objectives was developed.

Action Plan

The basic approach for determining which materials may be susceptible to sulfur induced corrosion was developed by a planning sequence that took into consideration the needs for inspection plan, examination methods, tooling/equipment, schedules, certified and/or technically qualified personnel, and plant conditions. As a result of these efforts, an Inspection and Test Plan was developed which incorporated 22 individual test plans involving thousands of components/parts. Selected engineering test requirements with specific acceptance criteria were developed for each test specification in a document called an Engineering Information Record (E.I.R.). The test and acceptance criteria are contained in reference report BAW 1727.

Procedures were developed at TMI using the EIR's as a base document. The engineering requirements of each EIR were incorporated into existing site procedures by use of Temporary Change Notice (TCN) or by issuance of site Special Test Procedures (STP). Procedures requiring qualifications of the inspection process were performed using actual components or parts and synthetic defects. The machining of these defects and qualifications of the process were made under a controlled QA Program with full demonstration of the capability of the inspection or test. Qualified and in the cases of NDE, certified personnel were used to conduct each test. For the special underwater, visual examinations, the examiners were first acclimated to the product and inspection by viewing hours of video tape from previous or similar examinations on the same product or like product.

Performance

On April 13, 1982, the TMI-1 reactor vessel head was removed to conduct the Task 7 inspection program. Since the damage had occurred to the OTSG's and the vessel had not been disassembled since the 1979 refueling outage, some special precautions were taken. These precautions included the ultrasonic inspection of the six (6) plenum lifting lug bolts. The plenum is second only to the vessel head in size and removal sequence during a refueling operation. An ultrasonic test was performed on the lifting bolts to insure integrity prior to lifting the thirty-eight (38) ton plenum. The lifting bolts had experienced exposure to the primary coolant system. The plenum was then lifted to the deep end of the refueling canal where a remote video inspection was conducted, resulting in over forty (40) hours of video tape.

Once the plenum was removed, many of the Task 7 inspections, such as ultrasonic inspection of plenum cover to cylinder bolts and video of top of core components, were conducted in parallel paths. While these parallel inspections were being performed, certain components/parts were removed from the plant for shipment to B&W Lynchburg Research Center for destructive testing. Those items removed and shipped to L.R.C. were:

- Three (3) pieces of vessel inner O-ring
- Regenative Neutron Source Retainer
- CRDM end closure

Once the top of the core was video inspected, two (2) un-irradiated fuel assemblies were removed from the core, one at a time, and given a complete inspection by GPUN and B&W Fuels Engineers for any abnormal appearances including an inspection for evidence of intergranular attack. As each of the un-irradiated fuel assembly was removed from the core the adjacent irradiated assemblies were observed by placing a remote camera in the vacated space. This part of the inspection also allowed visual access to some parts of the core baffles which were also inspected.

On May 7, 1982, the vessel head was replaced after completing Task 7 inspection.

In summary, the Task 7 Inspection Program employed approximately fifty (50) engineering and inspection personnel and took a three-week time period to complete. The program consisted of over 100 hours of visual/- video inspection of over 1000 feet of welds and their adjacent heat affected zone, six (6) liquid penetrant, nine (9) tubular and 158 bolting ultrasonic, two (2) eddy current, and five (5) radiographic inspections. Along with these items, the tech spec required exercising of the reactor vessel internal vent valves and, also, a functional check on incore detectors to determine if any primary leakage has occurred, was performed. In each and every case the results indicated no sign of intergranular attack (I.G.A.) or stress corrosion cracking.

III. THE DEVELOPMENT OF THE INSPECTION AND TEST PLAN

1. Task Objective

To assure that the reactor system components are qualified for continued safe operation, a program of inspections and tests was developed. The materials used to construct the components in the reactor coolant system were reviewed and selected for test based on a review of equipment specifications and the materials' susceptibility to attack. This selection process also took into consideration materials which had shown a tendency for this type of attack based on a literature search performed by B&W and EPRI[1]. Based on the classification of data concerning material/environment and stress conditions, recommended examinations were est[illegible]d which were used to verify that the components and other material conditions represented are suitable for continued safe operation.

2. Work Scope

The inspection plan was developed by Babcock & Wilcox and reviewed by GPUN for concurrence on inspection implementation. The work scope was separated into eight areas:

a. The component equipment specifications and layout and elevation drawings were reviewed to identify the material used and

NOTE 1: Literature Search on Laboratory of Cracking of Materials (Other than In 600) In Solutions Containing Sulfur Species by D. Cubicciotti-EPRI).

determine the exact location of the various components in the reactor coolant system. A summary of reactor coolant system materials table was developed for use on this project and is shown on Table III-1.

b. The materials used in the construction of the RCS components were evaluated as to their susceptibility to sulfur attack. This evaluation process was based on material stress and environmental conditions and the results of the Failure Analysis (Task 1) and some other studies made on the susceptibility of reactor coolant materials to solutions containing sulfur species.

c. Potential problem areas were identified for testing specific material/environment/stress combinations as a result of the component's location. This in turn was an important factor in reducing radiation exposure to personnel, both in the plant and in the laboratory. Other combinations were of a form or shape that they could not be reasonably tested with the more sensitive test methods. In those cases, other less sensitive inspections and tests were selected knowing that intergranular attack resulting in cracking would only be noticed if in some advanced state.

d. An inspection plan was developed based on a review of the materials involved and the accessibility of the materials within the system. From this plan a list of materials and their locations was generated. This list was used for determining the most accessible location for follow on site inspection based on the results of OTSG Failure Analysis (Task 1).

The task was subdivided into three parts as follows:

- ° RC System except OTSG(s) and Primary Side Auxiliary System
- ° Fuel
- ° OTSG Integrity - Supplement Report and not Task 7

e. Qualified individuals competent in the type of inspections were selected to the GPUN task group. Technical engineering specialists both from GPUN and B&W assisted in the evaluations of the results.

f. The inspection results were evaluated based on the acceptance criteria provided in B&W's Engineering Information Record, B&W Report BAW 1727, which made reference to ASME Section XI. In all cases, the current acceptance criteria was applied.

g. A contingency inspection plan was developed to determine what additional tests would be performed if IGSCC was discovered.

h. A collection of the inspection records and evaluations of the results were used to document the acceptability of the RCS.

3. Reactor Coolant System Materials

It was assumed that the RCS material in contact with reactor coolant may have been exposed to a sulfur contaminant. To assess which materials and material conditions would be susceptible to sulfur corrosion attack, a review of RCS material was conducted by B&W and tabulated along with the justification for selection in report BAW 1727. It is shown here in Table III-1.

4. Inspection and Test Plan

The inspection plan was developed to choose representative items in the Reactor Coolant System that are most likely to have suffered attack by the corrosive agent. The items chosen represented the most susceptible material conditions and reflected the environmental and stress concerns.

Since the known attack had occurred in the OTSG on stress-relieved Inconel 600 tubing material (PWHT) which was under stress in the cold shutdown condition. This same and other similar conditions were, therefore, to be suspected in other parts of the RCS. Other than the OTSG tube preload stress, possible areas of concern with respect to stress included bolting that have a steady load due to torqueing, residual stresses induced by welding, and force-fit items.

This plan included test of sufficient diversity to reflect the different materials, stresses, and environments that are present in the RCS. The premise for this logic is that generic material groups will behave similarly. Therefore, heat-to-heat variations were not considered unless evidence of intergranular attack and stress corrosion cracking existed. Under these conditions a more detailed failure investigation would be warranted.

The inspection plan was developed to also account for critical functions of the RCS items. The function of the pressure boundary, core support, and fuel integrity received the most emphasis. This was to determine the general condition of the system and, of course, because they are the most directly safety-related.

The areas of concern were approached by evaluating materials located in either of the three environmental conditions.

- o Primary coolant-air interface where most of the defects occurred in the OTSG.
- o Dry areas since the last refueling, but which have been previously wet.
- o Wet areas, covered by primary coolant.

Twenty-two inspection/tests were developed by B&W and approved by GPUN. The acceptance criteria to each is explained in B&W's engineering information records. An outline of this inspection is contained in Table III-2.

Table III-1 Summary of Reactor Coolant System Materials

RCS material	Condition	Representative item
Inconel 600, SG-166, -167, -168	As-ordered	RV CRDM nozzle, incore detector drive lines
	As-welded	RV CRDM nozzle to SS 304 flange
	PWHT/as-welded	HPI safe-end to SS 304 pipe, spray line nozzle safe-end to SS 316 pipe, decay heat nozzle safe-end weld
	Welded/PWHT	OTSG tubes, HPI safe-end, spray line nozzle safe-end, tubesheet cladding
Inconel 718	As-welded, annealed	RV O-ring
	Welded, age-hardened	Spacer grid, fuel assembly
Inconel X750	As-ordered	Fuel assembly holddown spring, RNS retainer spring, core support bolts
Inconel 660	As-ordered	Vent valve retainer spring
Stainless Steel, type 304	As-ordered (annealed)	RV CRDM flange, decay heat nozzle safe-end, CRDM leadscrew
	As-welded	RV CRDM flange (HAZ), CRDM motor tube, LPI piping weld
	PWHT/as-welded	HAZ locking cup welds on RV internals
	Welded/PWHT	Stainless cladding, plenum cylinder welds
	Cold-worked	Plenum lug bolts, plenum cover-to-cylinder bolts
	Cold-worked and welded	Control rod assemblies
Stainless steel, type 316	As-ordered (annealed)	Surge line pipe, spray line pipe
	As-welded	Surge line pipe, spray line pipe
	Welded/PWHT	None
Stainless steel, type 316L	As-ordered, as-welded	Pressurizer heater
	Casting	Fuel assembly end fittings
Stainless steel, type 403	As-ordered, condition A	CRDM Retainer assembly
17-4 PH (AMS 5643)	As-ordered	CRDM leadscrew coupling, makeup pump shaft

Table III-1 Summary of Reactor Coolant System Materials (Cont.)

RCS material	Condition	Representative item
Misc. stainless, cobalt, and Inconel alloys	As-ordered	CRDM internals
AMS 5737 C (A286)	As-ordered	Vent valve jack screw
Stainless steel, type 410	As-ordered	Decay heat pump shaft
Stellite No. 12	As-welded	RC pump rotor assembly
Zircaloy-4	As-ordered	Fuel rod
Braze material, 83Ni-7Cr-3Fe, 3B-4.5Si-.1 max C	As-welded	RV internals rod guide brazement
Stainless steel, type 304L	As-brazed	Spacer grids, rod guide segments
Stellite No. 6	As-welded	Vent valve bushing, CRDM internals
15-5-PH (AMS 5658)	As-ordered	Vent valve retaining ring
Stainless steel, type 431	As-ordered	Vent valve shaft

Table III-2 RCS Inspections and Tests

Item to be inspected	Type of inpsection	Justification
OTSG SS cladding, upper and lower heads (1)	Dye-penetrant, wipe sample	OTSG SS cladding is representative of cladding in the entire system in chemistry and degree of sensitization. Test is to support exclusion of carbon and low-alloy steels from requalification plan.
OTSG Inconel cladding, upper and lower tubesheets (2)	Dye-penetrant, wipe sample	Test for general attack on Inconel weld metal. Inconel cladding exists in the lower head of the RV and is not accessible unless the CSA is removed. Inconel cladding is sensitized.
Makeup nozzle safe-end, HPI nozzle safe-ends, spray line pressurizer nozzle safe-end, surge line pressurizer nozzle safe-end (3)	Radiograph and ultrasonic examination	A general check for thermal sleeve integrity. This also provides a sampling of Inconel above the water line, which has been heat-treated and in the as-welded condition. The surge line nozzle provides a sampling of SS 304 and SS 316 submerged, heat-treated Inconel and as-welded Inconel weld metal.
Leadscrew (4)	Wipe samples, visual	The leadscrew has been subjected to a wide range of environments over its length.
RV inner O-ring (5)	Lab. metallographic investigation, dye-penetrant, wipe sample of O-ring and underside of closure head	The O-ring is Inconel 718; it has been exposed to very high operating stress. Is in the dry condition and offers an opportunity to collect high concentrations of contaminant. Met sample to include the closure weld.
Motor tube (G)	Ultrasonic	The motor tube initially had known defects. The upper portion was in an environment similar to that of the OTSG tubes. Material is SS 304. UT to include upper tube-to-terminal forging weld.
CRDM end Fitting (7)	Dye-penetrant. lab. metallography, wipe sample per Task 1	Piece is being removed for leadscrew access. This piece is SS 304 and is near the level of the upper tubesheet air water interface.
Holddown bolts of plenum lift lugs (8)	Ultrasonic	Typical A-193 B8 (SS 304) bolting material is currently dry. Ensure sound prior to plenum lift.

Table III-2 RCS Inspections and Tests (Cont.)

Item to be inspected	Type of inpsection	Justification
Top of core and control components (9)	Video	General condition of core components, including holddown springs and upper end fittings and loose parts. Holddown springs are Inconel X750, upper end fitting is SS 304.
Fuel assembly, control components (10)	Video	General condition of FA included integrity of spacer grids. Spacer grids are Inconel 718. General condition of weid attachments and upper end of rods.
RNS retainer (11)	Dye-penetrant, lab metallography	Easily removable and replaceable. Represents SS 304 and X750 in cold shutdown stressed conditions (submerged, as is fuel assembly).
Core support shield-to-core barrel bolt (12)	Ultrasonic	Typical X750 bolting material in internals. Significant structural number with high tensile stress.
Lower bolting rings in RV internals and lower vessel head (13)	Video	General inspection for condition of locking devices and possible bolt failures. General inspection for damage and loose parts
Reactor internals baffle plate region (14)	Video	General inspection for condition of SS 304 bolts in baffle region and check of bolt locking devices
CRDM nozzles to SS flange (15)	Eddy-current	Non-stress-relieved SG-166 and SS 304 in the as-welded condition. Currently above the RCS water line.
Plenum assembly (16)	Video of accessible portions on plenum stand in deep end of canal	Inspection for general condition of SS 304 welded sheels and bolting rings.
Bolts: plenum cylinder to plenum cover (17)	Ultrasonic where possible	General check on SA-193 B8 bolting material. Accessible area and not on critical path.
Vent valves and core support shield ID (18)	Video, Tech Spec exercise	Vent valves contain suspect materials. Inspection required for future operation to ensure integrity and function of valves.

Table III-2 RCS Inspections and Tests (Cont.)

Item to be inspected	Type of inpsection	Justification
Low-pressure injection pipe welds (20)	Ultrasonic (selected welds)	Some of these welds had known cracks which were believed to be from sulfur corrosion. Compare to previous UT inspection baseline.
Incore detectors (21)	Functional	These items must be verified functionally for startup. Contain representative materials of submerged items.
Incore detector sheath (22)	Dye-penetrant, wipe sample	Representative of cold-drawn Inconel 600. Has seen a variety of water levels.
Vent valve thermocouple nozzle (23)	Eddy-current	Provides a sample of Inconel 600 in cold-drawn condition and as-welded above water line.

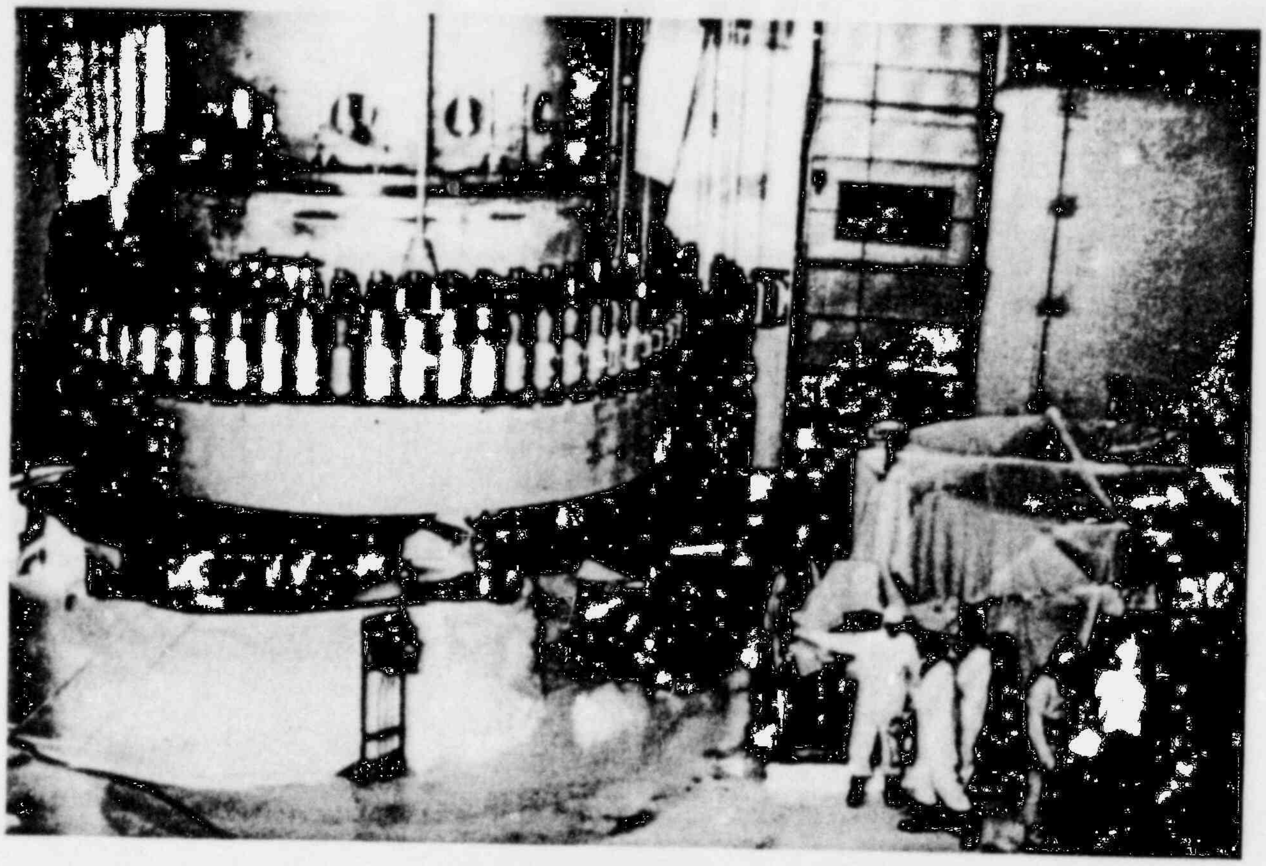

FIG. 1

PLACEMENT OF 158,300 lb. RV HEAD ON HEAD STAND

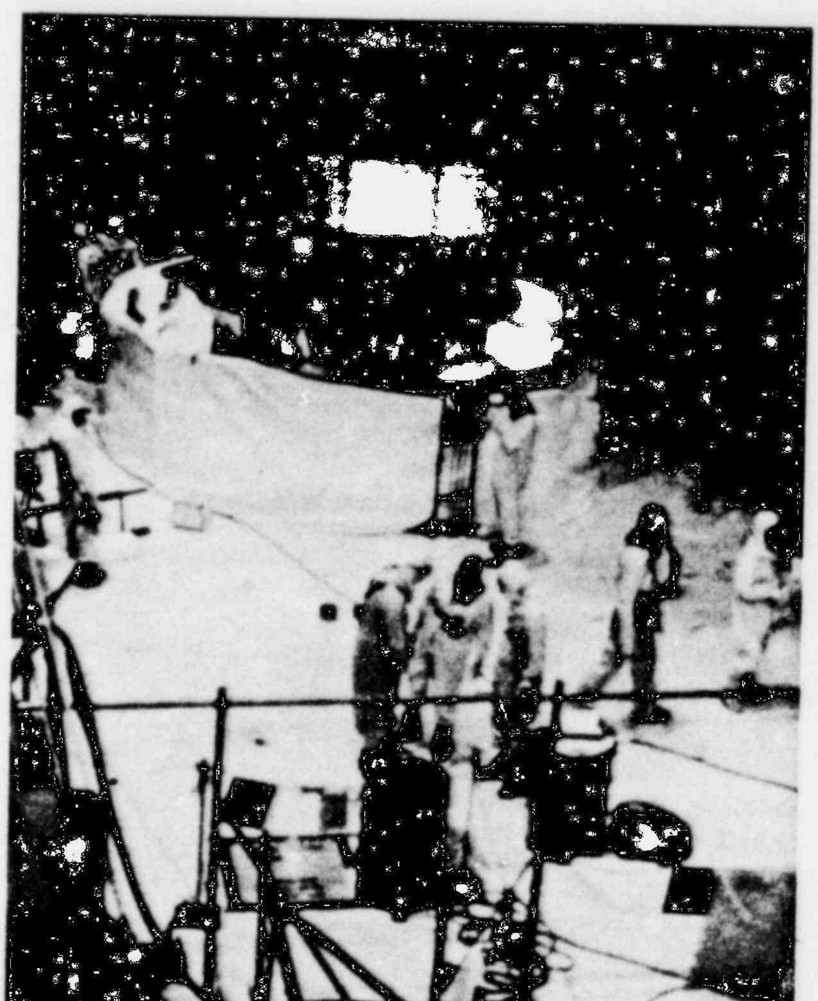

FIG. 2

RAD-CON TECHNICIANS ARE SURVEYING RADIOLOGICAL FIELDS AROUND HEAD STAND

IV. METHODS OF INSPECTION

Several different types of inspection examinations were used to accomplish the objective of Task #7. This section shall explain the logic for their selection, the capabilities of these methods, the technical aspects for accomplishing this task, and the technical personnel qualifications employed for this effort.

The non-destructive examination methods used for this program were; ultrasonic, liquid penetrant, eddy current, radiography, visual, and wipe sampling. Other examinations included functional check on equipment and destructive metallurgical examinations, both at the TMI-1 site and at B&W Research Laboratory at Lynchburg. The selection of examinations was governed by factors relating to the type of material, geometry of material, location and accessibility, and radiological control limitations. The following paragraphs are technical information/data for each discipline:

1. Ultrasonic Examination Method (UT)

   A volumetric inspection employed for detecting flaws in a component's weld, heat affected zone (HAZ), and base metal region. This examination had the capability of detecting indications having a depth of 10% of the minimum wall thickness for tubular and planar surfaces and 20% of the diameter of the bolts. UT was chosen to investigate the possible material failures for components located in all three environmental states.

a. The pressurizer spray nozzle safe end (3B) and the three CRDM motor tube extensions (6) are located in the first area of concern, the coolant/air interface zone.

b. The make up piping nozzles, (3A) plenum lifting lugs bolts (8), and the plenum cover to plenum cylinder bolts (17) were located in a basically dry region.

c. The pressurizer surge nozzle (3C), core barrel bolts (12), and the low pressure injection pipe welds (20) have been basically covered by water.

The equipment employed was ultrasonic flaw detectors capable of generating frequencies in the required range. The flaw detectors were calibrated to assure that linearity requirements were met prior to use. All ultrasonic transducers/search units employed in the test had certification/documentation prior to use. This certification contained as a minimum, a real time wave form and frequency spectrum photograph. All these requirements were met and adhered to.

The calibration standards for the tests mentioned above, were either fabricated specifically for this task or obtained, from the standards used during normal ISI examinations. Test 3A, 3B, 3C, 6 and 20 employed ISI standards which were of the same material, thickness and diameter. The standards contained side drilled holes located at the prescribed depths and locations as specified by the ASME Code.

Test #8, 12, and 17 required fabrication of new standards. For Test #8, 12, and 17 an actual part was used, material certifications were obtained, and several sawtooth reflectors were machined parallel to the test surface at locations and to depths prescribed by B&W.

The examinations of Tests 8, 12, and 17 were carried out by the use of a straight (normal) beam technique. The examination of Test 3A, 3B, 3C, 6, and 20 used an angle beam technique as well as a straight beam technique. The use of the straight beam technique for Test 3A, 3B, 3C, 6, and 20 was to confirm actual wall thicknesses and to develop the actual weld profile. In the angle beam examination, a system confirmation check (exit point and actual angle) was performed prior to each day's usage.

Scanning was performed in all possible directions, (CW, CCW, axial, circum.) from all accessible surfaces. A 100 percent coverage was attempted in all tests while maintaining a minimum of 25 percent overlap of the search unit. The ultrasonic couplant when used was certified for use on stainless steels. All temperature requirements were met as well as the proper forms for documenting the examination were completed.

2. Liquid Penetrant Examination (PT)

The Liquid penetrant Examination method is classified as a surface examination. This method was chosen to investigate the presence of any surface degradation that may have propagated in the three special interest regions. The acceptance criteria was in accordance with the ASME Section V Code of 1977 through Summer 1978 addenda and special consideration was given to the welds of the secondary oversheath to assembly oversheath of the incore detectors. These welds were evaluated to a more stringent tolerance.

Items examined by this method were:

a. Upper OTSG Inconel (tube sheet) and stainless steel (lead) weld cladding (1) & (2) and the incore detectors closure and sheath (22). These were samples from the coolant/gas interface region.
b. Incore detector (22) the dry region portion make up nozzle (3A). A known related problem of cracking in other plants with similar designs was prevalent (NRC commitment).
c. Lower OTSG cladding surface and incore detector portions from the wet regions.

The cleaning, developing, and penetrant materials used in this examination are certified for use on stainless steels. All cleaning, applications of penetrant, developer, removal of penetrant, and post cleaning was performed in accordance to the appropriate procedure. All time factors and application methods were strictly adhered to. Additional lighting was employed during the entire examination, also the use of a 1/32" black line on an 18 percent neutral gray card was verified as capable of being distinguished.

All temperature requirements were maintained prior to and during the examination. All pertinent data was recorded on the appropriate forms specified.

3. Eddy Current Examination Method (EC)

The Eddy Current Examination method is classified as both a volumetric and surface examination. It was proven to be a most meaningful method during the inspection of the OTSG tubes. The ID surfaces of the RV vent valve thermocouple (23) and the CRDM nozzle (15) were the areas of special concerns we felt required this method of surface examination. Both components are located in the basically dry of coolant area. This examination had the capability to determine if surface defects, at least 10% of wall thickness and 3/8" long in the circumferential or axial direction are present on the inside diameter of the nozzle.

The equipment employed to perform the eddy current examination was verified to be in proper working order and within calibration frequency. The eddy current calibration standards were manufactured by B&W specifically for this task. All calibration standards employed were verified to be of the same materials, size and nominal wall thickness as that of the product being examined. Artificial reflectors were installed at the prescribed locations and dimension required. Test #15 employed an actual CRDM nozzle as its calibration standard while Test #23 incorporated a pipe of the same diameter and wall thickness as the vent valve thermocouple undergoing examination. The examinations performed were a multi-frequency inspection, incorporating an oscilloscope (MIZ-12), frequency mixer, tape recorder, and strip chart recorder. The probes employed were of the differential mode and were essentially the same size as the inside diameter of the product being tested with allowances for wobble. Calibration was performed employing the entire system of that to be used in the examinations. All pertinent information required to calibrate and perform the examinations was recorded on the applicable calibration/data forms. Magnetic recording tape recording tape and the strip chart print-out containing the calibration and inspection results were stored with the calibration/data forms. The magnetic recording tape is not considered a permanent plant record, therefore permanent storage is not a requirement.

4. Radiographic Examination Method (R.T.)

The above method is a volumetric type of examination that produces a visual image of the test specimen. For this reason, this method was chosen to validate the structural integrity of the thermal sleeves for the safe end nozzles. The pressurizer spray nozzle (3B) and the three make up nozzles (3A) were located in a coolant/gas interface and departure of the coolant dry area respectively. The special acceptance criteria was to determine a sound thermal sleeve fit-up. Therefore, the quality of the radiograph was not measured by a penetrometer only, but rather by the definition, contrast, and geometric unsharpness of the radiograph. The Radiographic examination employed was performed in a conventional manner incorporating a radioisotope (IR^{192}) along with extra fine grain film and intensifying screens. A double wall exposure technique with single wall viewing was performed. An acceptable geometric unsharpness factor was maintained and all developing was performed by hand. The evaluation of all radiographs was by certified personnel.

5. Visual Examination Method (V.T.)

Visual inspection is a surface type of examination which requires the sense of sight, an adequate light source, and sufficient contrast. Surface discontinuity, abnormal configurations, and conditions are the attributes often evaluated.

Because of the shielding requirements necessary for fuel and reactor core component inspection, remote visual/video inspection method was chosen as the principle examination.

Concern for the fuel integrity (10A, 10B, 10D) was the major reason for incorporating these inspections into the inspection plan. The areas of interest were submerged by the reactor coolant; the tope of core control components (9), the baffle plant region (10C) and the annulus between CSA and RV (13 & 14). Areas of similar conditions, even though they were dry of reactor coolant, were the plenum assembly (16) and the vent valve assembly (18). V.T.-1 Direct Visual - this category of visual examination was performed when the eye could be placed within 24 inches of the surface to be examined and at an angle not less than 30° to the surface.V.T.-1 Remote Visual - this type of examination was employed when using aids, such as video T.V. cameras, telescopes, or other suitable viewing devices, provided such devices have a resolution capability at least equivalent to that attainable by direct visual examination.

The visual examinations for Tests 9, 10A, 10B, 10C, 13, 14, and 16 were conducted by the V.T.-Remote Visual method. All of the above tests were conducted using T.V. cameras having capabilities of video tape (for review and record) and audio for voice annotation.[2]

The examinations were accomplished with trained camera handlers, all manual adjustments were made to achieve the greatest possible resolution with the equipment being employed. Once this was obtained and the component requiring examination was under viewing, the video tape was started and voice communications were commenced. Voice communications were limited to the area/location of the actual picture being transmitted/received.

Two (2) monitor stations were established, one (1) station for the camera handlers and the other station for the camera operators and examiner (when required). The camera handler's

station contained only a video monitor and voice communications only to the camera operator/examiner. The camera operator's/examiner's station contained all the necessary electronic equipment to perform video taping and voice annotation of the tape, focusing and adjusting of the cameras. Also

NOTE 2: The recorded video tapes for items included in this inspection program shall not be treated as a permanent plant record.

available was a video monitor whereby the examiner would perform the actual visual acceptance/rejection of the examination. Voice communication between the camera handlers and operators/examiners was used for coordination on locating the components and when a satisfactory picture was attained.

Auxiliary lighting was required for all video examinations. Video assistance was also required to assist in the location of the search unit in Test #13.

6. Wipe Sampling Method

The wipe sampling method was performed prior to non-destructive examination other than visual. Pre-clean wipes individually bagged and labeled with a batch number were supplied by B&W. The pre-moistening agents were: demineralized water or alcohol/acetone and demineralization water. An even pressure was applied to the surface collecting any deposits located in the area of interest. These samples were bagged and labeled with the appropriate identification. Storage for these samples was maintained in a segregated area until shipping arrangements were made for B&W Reasearch Center. At the Research Center, the samples were chemically analyzed to determine the concen- tration of any found aggressive solution.

The Technical Personnel Requirements were:

1 Non-destructive Examination Personnel

The NDE for Task 7 was performed by GPUN individuals certified to the requirements of the GPUN in-house program which satisfied ASNT-TC-1A. NDE certification packages for qualified contractors were received, reviewed by GPUN Lead Level III and approved to the same requirements.

Applicable NDE personnel satisfied the basic requirements of sufficient education, training, experience and were qualified to the NDE level required. Satisfaction of these requirements assured an understanding of the test principles, procedures and applications of test methods utilized.

2 Technical Specialist

Fuel Examination: The fuel examinations were conducted by personnel having an in-depth background in underwater fuel examinations and knowledge of the product. They are qualified and experienced in fuel mechanical design, performance and test evaluation of PWR fuel. These requirements were necessary because underwater visual examination of nuclear fuel elements for unusual signs of corrosion attributable to sulfur contaminants is a subject examination. This relies heavily upon technical expertise and experience gained from this type of examination in order to recognize and assess abnormal conditions.

Reactor Operator: The performance of Inspection 10D, Control Component was closely monitored by a licensed reactor operator. The TMI-1 Technical Specifications stipulate this requirement whenever a reactivity change (control rod movement) is executed.

Video Equipment: Technical support was required to assist in the remote video inspections. Underwater camera manipulation was performed by individuals experienced in this craft. Their knowledge of component locations and identification of the inspection areas was also a valuable asset in performing the inspection. This experience was the result of previous inspections on other B&W designed plants and/or at TMI.

The technicians that maintained the video system during this long period of examinations were chosen from the TMI-1 Instrumentation and Control Department. The candidate's ability to set up the system and troubleshoot any technical difficulties was the basis for their selection.

3 Operators:

Functional Checks: The exercising of the vent valves and the continuity check of the incore detectors were performed to approved site procedures. The individuals performing these routine operations were knowledgeable in the requirements of the procedures and competent in the implementation of this task.

All other operator's functions required for this task were done in accordance with approved site procedures. Certification of training and experience for these persons are available in site records.

4 Engineers:

Procedures: The development of procedures was carried out by combined engineering efforts employing the talents of GPUN and B&W. The experiences sort for this task were plant design, environmental and operational stress, testing of materials and planning and scheduling.

A list of personnel is contained in Appendices A and B.

V. RESULTS OF INSPECTIONS

The materials inspected or tested to determine integrity were each examined as part of a separate task/inspection area. These areas were not chosen based on the material classification but were grouped by their physical location, accessibility and inspection method. Although this facilitated the actual performance of the inspection program, it also resulted in twenty-two summary reports. None of these reports really stand alone as a verification of a particular material or component and must be considered in relation to each other as part of an integrated program.

This section provides an integration of the results from each area into a format consistent with the original selection process as outlined earlier. A table summary has been used to list the inspection program results and includes the information most relevant to the Task 7 objectives. Additional information on each specific inspection or test can be found in the individual areas summaries which are referenced in the appendix section; however, it is to be re-emphasized that no single inspection was designed to stand by itself as conclusive proof that the RCS does not show a condition similar to that experienced by the OTSG tubes.

The results of the reactor inspection program are categorized by material type in Table V-1, Material Results Summary, with further subcategory divisions to provide a comprehensive tabulation of the key parameters for each material. A general description of each category is as follows:

1. Material - The typical material name such as inconel, stainless steel, or carbon steel. Also included in most cases is the material type and specification (i.e., 304 SST, I-600, etc.) The standard material classification which provides a reference to the materials composition and initial fabrication.

2. Condition - Refers to the actual installed material condition which summarized the heat treatment or subsequent metallurgical changes performed after initial fabrication.

3. Environment - The physical conditions present at the examined material's location during the time period of interest.

4. Mechanical Stress - A very general classification of the mechanical stress placed on the material during the time

period of interest. This does not reflect the residual type stresses which may be present due to cold working or welding.

5. Method of Inspection - The inspection technique used for the particular material exam. A detailed description of all the methods utilized is provided in Section D.

6. Inspection or Test Number - The task or area number given to each inspection. The individual test summaries are included in BAW 1727.

7. Results - The inspection results as they relate to the task objective of defining the scope of the IGSCC characteristic of the OTSG tube degradation.

8. Remarks - General information about a particular material inspection which is considered to be of interest.

The majority of materials have been in service since the initial construction of TMI-1 and have been subject to varying degrees of irradiation as determined by their physical location. The exceptions to this are components which were installed during the refueling outages, such as fuel assemblies or expected core component replacements.

The "time period of interest" is that time span immediately prior to, and subsequent to the OTSG tube degradation. This is of special importance when viewed in conjunction with the environmental or mechanical stress categories of Table V-1. These references are limited to those conditions present during this time and do not represent the materials' entire history at TMI.

TABLE V-1

MATERIAL SPECIFICATION	CONDITION	ENVIRONMENT	APPLIED MECHANICAL STRESS	INSPECTION METHOD	TEST NO.	RESULT	REMARKS
Inconel	PWHT	Wet Dry	Low	PT	2	Accept	Cladding OTSG
600	PWHT	Wet	Low	PT	2	Accept	Cladding OTSG
SB-166	PWHT-Welded	Wet	Low	UT	3A	Accept	Safe-End
SB-167	PWHT-Welded	Wet	Low	UT	3A	Accept	Safe-End
SB-168	PWHT-Welded	Wet	Low	UT	3A	Accept	Safe-End
	PWHT-Welded	Wet	Low	UT	3A	Accept	Safe-End
	PWHT-Welded	Wet	Low	UT	3B	Accept	Safe-End
	As Welded	Wet Dry	Low	UT	6	Accept	Bi-Metallic Weld
	As Ordered	Wet Dry	Moderate	ECT	15	Accept	CRDM Nozzle
	As Welded	Wet Dry	Low	ECT	15	Accept	Bi-Metallic Weld
	As Ordered	Wet Dry	Low	PT	22	Accept	Incore Detector
	As Welded	Wet Dry	Low	PT	22	Accept	Incore Detector
	As Welded	Wet Dry	Low	Functional	21	Accept	Incore Detector
	As Ordered	Wet Dry	Moderate	ECT	23	Accept	Thermocouple Nozzle
	As Welded	Wet Dry	Low	ECT	23	Accept	Bi-Metallic Weld
Inconel	As Ordered	Wet Dry	High	Lab Analysis	5	Accept	O-Ring Tube
718	As Welded	Wet Dry	High	Lab Analysis	5	Accept	O-Ring Weld
	As Ordered	Wet	Low	Visual	10A	Accept	Spacer Grid
	Cold Worked	Wet	High	Visual	10A	Accept	Spacer Grid

TABLE V-1

MATERIAL SPECIFICATION	CONDITION	ENVIRONMENT	APPLIED MECHANICAL STRESS	INSPECTION METHOD	TEST NO.	RESULT	REMARKS
	As Welded	Wet	Moderate	Visual	10A	Accept	Spacer Grid
	As Ordered	Wet	Low	Visual	10B	Accept	Spacer Grid
	Cold Worked	Wet	High	Visual	10B	Accept	Spacer Grid
	As Welded	Wet	Moderate	Visual	10B	Accept	Spacer Grid
x750	Drawn: Cold Worked	Wet	High	Visual	9	Accept	Hold Down Spring
	Drawn: Cold Worked	Wet	High	Lab Analysis	11	Accept	RNS Retainer Spring
	As Ordered Cold Worked	Wet	High	UT	12	Accept	Core Barrell Bolts
660	Cold Worked	Wet Dry	High	Visual	18	Accept	Vent Valves Retainer Spring
668	As Ordered	Wet Dry	High	Visual	13/14	Accept	120 Lower Grid Sheet to Thermal Shield Bolts 74/120 Accessible
	As Ordered	Wet	High	Visual	13/14	Accept	108 Lower Grid Shell to Core Barrel Bolts 72/108 Accessible
668	As Ordered	Wet	High	Visual	13/14	Accept	20 Bock Assembly 2/20 Accessible
	As Ordered	Wet	High	Visual	13/14	Accept	96 Flow Distributor to Lower Grid Shell Forging Bolts 64/96 Accessible

MATERIAL SPECIFICATION	CONDITION	ENVIRONMENT	APPLIED MECHANICAL STRESS	INSPECTION METHOD	TEST NO.	RESULT	REMARKS
Stainless Steel	Welded-PWHT	Wet Dry	Low	PT	1	Accept	Cladding OTSG
F-304	Welded-PWHT	Wet	Low	PT	1	Accept	Cladding OTSG
	As Ordered	Wet Dry	Low	Wipe	4	Accept	Lead Screw
	As Welded	Wet Dry	Low	UT	6	Accept	Motor Tube Extension
	As Ordered	Wet Dry	Low	Lab Analysis	7	Accept	CRDM Insert
	Cold Worked	Wet Dry	Low	UT	8	Accept	Lifting Lug
	Casting: Plate Welded	Wet	Low	Visual	10A	Accept	End Fitting
	Casting: Plate Welded	Wet	Low	Visual	10B	Accept	End Fitting
	As Ordered	Wet	Low	Visual	10C	Accept	Baffle Plate
	As Welded	Wet	Low	Visual	10C	Accept	Block Welds
	Welded Cold Worked	Wet	Low	Visual	10D	Accept	Control Rod Assembly
	Welded Cold Worked	Wet	Low	Visual	10D	Accept	APSR
	Cold Worked Annealed Plate	Wet	Moderate	Lab Analysis	11	Accept	Retainer Spring Load Arm

TABLE V-1

MATERIAL SPECIFICATION	CONDITION	ENVIRONMENT	APPLIED MECHANICAL STRESS	INSPECTION METHOD	TEST NO.	RESULT	REMARKS
Stainless Steel F 304	As Ordered	Wet	Low	Visual	10C	Accept	Entire Vertical Length of Each Baffle Plate 75% Accessible
	As Ordered	Wet	Low	Visual	10C	Accept	Flow Hole and Flow Slots 100% Accessible
	As Ordered	Wet	Low	Visual	10C	--	Vertical Gap Between Baffle Plate 0% Accessible
	As Ordered	Wet	Low	Visual	10C	Accept	Former Bolt 21/21 Accessible
	As Ordered	Wet	Low	Visual	10C	Accept	5th Row Former Bolts 3/3 Accessible
	As Ordered	Wet	Low	Visual	10C	--	Corner Baffle to Baffle Bolts 0% Accessible
	As Ordered As Welded	Wet	Low	Visual	10C	--	Lower Grid Pad and Weld 0% Accessible
	Welded PWHT	Wet	Low	Visual	10C	--	Top Rib 0% Accessible
	Welded PWHT	Wet	Low	Visual	13/14	Accept	OD Upper Flange and Shield Cylinder Weld 15% Accessible
	Welded PWHT	Wet	Low	Visual	13/14	Accept	OD Lower Flange: Shield Cylinder Weld 15% Accessible
	As Ordered PWHT	Wet	Low	Viaual	13/14	Accept	OD Surface Cylinder Upper and Lower Flange 15% Accessible

TABLE V-1

MATERIAL SPECIFICATION	CONDITION	ENVIRONMENT	APPLIED MECHANICAL STRESS	INSPECTION METHOD	TEST NO.	RESULT	REMARKS
Stainless Steel F-304	PWHT	Wet	Low	Visual	13/14	--	Outlet Nozzle and Shield Cylinder Welds 0% Accessible
	As Welded	Wet	Low	Visual	13/14	--	Flow Deflectors and Attachment Welds 0% Accessible
	As Ordered As Welded	Wet	Low	Visual	13/14	--	Surveillance Tube Assembly 0% Accessible
	Welded PWHT	Wet	Low	Visual	13/14	Accept	Upper and Lower Cylinder Section Weld 10% Accessible
	As Ordered PWHT	Wet	Low	Visual	13/14	Accept	OD Surface of Thermal Shield % Undetermined
	As Ordered	Wet	Low	Visual	13/14	Accept	Shock Pad Assembly 8/12 Accessible
	As Ordered As Welded	Wet	Low	Visual	13/14	Accept	Guide Block Assembly 16/24 Accessible
	Welded PWHT	Wet	Low	Visual	13/14	Accept	OD Surface of Lower Grid Shell Forging % Undetermined
	As Ordered	Wet	Low	Visual	13/14	Accept	Flow Holes 32/156 Accessible
	As Welded	Wet	Low	Visual	13/14	Accept	Locking Clip Welds
	As Ordered	Wet	Low	Visual	13/14	Accept	Locking Clips 80% Accessible

TABLE V-1

MATERIAL SPECIFICATION	CONDITION	ENVIRONMENT	APPLIED MECHANICAL STRESS	INSPECTION METHOD	TEST NO.	RESULT	REMARKS
Stainless Steel F-304	As Welded	Wet	Low	Visual	13/14	Accept	Locking Clip Welds
	As Ordered	Wet	Low	Visual	13/14	Accept	Locking Clips 60% Accessible
	As Welded As Ordered	Wet Dry	Low	ECT	15	Accept	CRDM Nozzle
	As Ordered	Wet Dry	Low	Visual	16	--	Plenum Lifting Lug Not Accessible
	Welded PWHT	Wet Dry	Low	Visual	16	Accept	Cover Plate 25% Accessible
	As Welded	Wet Dry	Low	Visual	16	Accept	Cover Plate To Grid Weld 20% Accessible
	As Welded	Wet Dry	Low	Visual	16	Accept	Fillet Weld Cover Plate 47/69 Accessible
	Welded PWHT	Wet Dry	Low	Visual	16	--	Grid Ribs, Rib to Rib Weld, Rib to Flange Not Accessible
	As Ordered As Welded	Wet Dry	Low	Visual	16	--	(32) Clamping Pads Not Accessible
	As Ordered	Wet Dry	Low	Visual	16	Accept	Key Way 4/4 Accessible
	As Welded Welded PWHT	Wet Dry	Low	Visual	16	Accept	Weld Upper and Lower Flange to Cylinder 100% Accessible
	As Welded	Wet Dry	Low	Visual	16	Accept	LOCA Bumper 13/13 Accessible
	Welded PWHT	Wet Dry	Low	Visual	16	--	Reinforcing Plate and Weld 0% Accessible

TABLE V-1

MATERIAL SPECIFICATION	CONDITION	ENVIRONMENT	APPLIED MECHANICAL STRESS	INSPECTION METHOD	TEST NO.	RESULT	REMARKS
Stainless Steel F-304	As Ordered Cold Worked	Wet Dry	High	Visual	16	Accept	Upper Flange to Cover Bolt 39/64 Accessible
	As Ordered Cold Worked	Wet Dry	High	Visual	16	Accept	Lower Flange to Upper Grid Assembly Bolts 22/36 Accessible
	As Welded	Wet Dry	Low	Visual	16	Accept	CRGT 23/69 Accessible
	As Ordered	Wet Dry	High	Visual	16	Accept	1/2" Diameter Screws 46/92 Accessible
	As Ordered	Wet Dry	High	Visual	16	Accept	Pipe Weldment to Spacer Casting 3/8" Screw 184/184 Accessible
	As Ordered	Wet Dry	High	UT	17	Accept	Cover-Cylinder Bolts
	Welded PWHT	Wet	Low	Visual	18	Accept	(8) Vent Nozzle and Welds
	Welded PWHT	Wet	Low	Visual	18	Accept	I.D. Core Support Shield (8) Vent Nozzle and Welds
	As Ordered	Wet	Low	Functional	18	Accept	Vent Valves 100% Accessible
	Welded PWHT	Wet	Low	Visual	18	Undetectable	I.D. Shield and Upper Flange Weld
	Welded PWHT	Wet	Low	Visual	18	Undetectable	I.D. Shield and Lower Flange Weld

TABLE V-1

MATERIAL SPECIFICATION	CONDITION	ENVIRONMENT	APPLIED MECHANICAL STRESS	INSPECTION METHOD	TEST NO.	RESULT	REMARKS
Stainless Steel F-304	Welded PWHT	Wet	Low	Visual	18	Undetectable	Shield Cylinder and Outlet Nozzles Welds
	As Welded	Wet	Low	Visual	18	Accept	LOCA Bumper Parts 26/26 Accessible
	As Welded	Wet	Low	Visual	18	Accept	Lifting Lugs and Weld to Upper Flange 3/3 Accessible
	Welded PWHT	Wet	Low	Visual	18	Accept	I.D. Upper and Lower Flange to Cylinder 15% Accessible
	As Welded	Wet/Dry	Low	UT	20	ISI	LPI Piping Weld
	As Welded	Wet	Low	Functional	21	Accept	Incore Detector
	As Welded	Wet/Dry	Low	ECT	23	Accept	Thermocouple Nozzle
F-304L	As Brazed	Wet	Low	Visual	16	Accept	Spacer Plate
	As Brazed	Wet	Low	Visual	16	Accept	Rod Guide Segment
	As Brazed	Wet	Low	Visual	16	Accept	Spacer Plate
	As Brazed	Wet	Low	Visual	16	Accept	Rod Guide Segment

TABLE V-1

MATERIAL SPECIFICATION	CONDITION	ENVIRONMENT	APPLIED MECHANICAL STRESS	INSPECTION METHOD	TEST NO.	RESULT	REMARKS
Stainlss Steel 316	As Welded	Wet	Low	UT	3C	Accept	Surge Nozzle Safe End
	As Ordered	Wet	Low	UT	3C	Accept	Surge Pipe
316L	As Ordered	Wet	Low	Visual	9	Accept	Spring Retainer
	As Ordered	Wet	Low	Visual	9	Accept	End Fitting
	As Ordered	Wet	Low	Visual	9	Accept	Spiders
	Casting	Wet	Low	Visual	10A	Accept	End Fitting
	Casting	Wet	Low	Visual	10B	Accept	End Fitting
Zircaloy	Cold Drawn As Ordered	Wet	Low	Visual	10A	Accept	Fuel Rod
4	Cold Drawn As Ordered	Wet	Low	Visual	10B	Accept	Fuel Rod
	Cold Drawn	Wet	Low	Visual	10A	Accept	Guide Tube
	Cold Drawn	Wet	Low	Visual	10B	Accept	Guide Tube

VI. CONCLUSIONS

Conclusions are listed in three groups identified by the areas that had a different environmental impact on the represented materials. Each conclusion listed is supported by reference to the specific test result contained in Appendix C:

1. Primary coolant/gas interface area similar to OTSG defect zone.

   a. Inconel and 308 Stainless Steel Cladding - Although some minor pitting indications were found, all test areas were penetrant inspected and found satisfactory to the requirement of NB-5110 and the acceptance limits of NB-5350 of the ASME Code. No evidence of intergranular attack or evidence of cracking was noted. It is concluded from this testing that all the cladding areas in primary system subjected to this environment are acceptable.

   - See test results - 1 & 2.

   b. CRDM End Fitting - Wrought Stainless Steel 304 material ordered in the as annealed condition reveals no evidence of general intergranular attack using destructive metallurgical examination, including EDAX and Electron Microscopy. Annealed 304 SS subjected to this environment is acceptable.

   - See test results 7.

c. Motor Tube on CRDM Extensions - Motor tubes were made of welded Inconel 600 and SA 312 Grade 304, were ultrasonically tested in the weldment and heat affect zone for two distinct welds per extension tube, and found to be defect free. In the case of one motor tube extension, ultrasonic testing confirmed an original manufacturing defect which was evaluated and accepted by radiographic inspection. These results, when compared with items (d) and (e) below, confirms that welded 304 SS under this environment is acceptable.

- See results Test 6.

d. Pressurizer Spray Nozzle Safe End - Areas of interest included 304 stainless steel and safe end material made of B166. The weld and associated heat affect zones were both radiographically and ultrasonically tested, and found to be defect free. These results confirm the conclusion that Inconel and 300 series stainless steels are acceptable under these environmental conditions.

- See results Test 3B.

e. Incore Detector Closure and Sheath - One detector was penetrant inspected throughout the wetted portion of the assembly closure and a second detector over two feet from either side of the observable water line. The inspections were evaluated to an acceptance standard which permitted essentially no defect. The materials are Inconel 600 and included select welds which were found to be defect free. Although penetrant inspection is not considered the most sensitive testing available, it is apparent that the results are consistent with the test results above.

- See test results 22.

2. Areas which were basically dried out:

   a. CRDM Nozzle in the Reactor Vessel Head - Inconel 600 (B167) tube welded to the head and to an A-182 F-304 stainless steel flange was eddy current tested and found to be defect free.

      - See test results 15.

   b. Thermocouple Nozzle Welded in Reactor Vessel Head - This item was exposed to essentially the same material history including post weld heat treatment as the OTSG tubes but had minimal axial loading. The nozzle was eddy current tested and found to be defect free. Both tests (a) and (b) suggest that Inconel 600 is acceptable under the given environmental conditions including only residual stresses from welding.

      - See test results 23.

   c. Plenum Lifting Lug Bolts and Plenum Cover to Cylinder Bolts - These bolts were manufactured from 304 stainless steel and were highly stressed. The material is typical of several hundred other bolts in the reactor vessel. The bolts were ultrasonically tested and found defect free. These results would imply that 304 SS material under relatively high stress is not subject to intergranular stress corrosion cracking. It should also be noted that this material is not expected to be sensitized.

- See test results for 8 and 17.

d. Incore Detector Sheath - Welded Inconel 600 tubing was penetrant inspected and found defect free.

   - See test results for 22.

e. Make up Nozzles - All four make up nozzles were ultrasonically and radiograph tested in areas around the B-166 safe end, heat affect zone, the 304 stainless steel pipe and heat affect zone. The results indicate that this material was acceptable under the specified environment including the residual weld stresses noted.

   - See test results for 3A.

f. Reactor Vessel O-Ring - The reactor vessel o-ring made of welded inconel 718 tubing with a stagnant environment on the inner diameter surface, was an excellent candidate to test the susceptibility of this material to this type of attack. The o-ring had two weldments and was subjected to high tensile and compressive stresses. Metallurgical examination of the x-section area and reverse bending of exposed surfaces revealed no sign of intergranular attack.

- See test results for 5.

g. Plenum Assembly - Although this test was limited to visual examination (1 to 3X), estensive coverage of significant portions of 304 SS plates and forging accompanied by examination of several weldments revealed that the areas of interest did not reveal concerns or areas considered to be unusual for this type of history. Note also that the assembly is exposed to a heat treatment of 850 $\pm$ 25°F for 48 hours.

- See test results 16.

h. Vent Valve Assembly - A detailed video inspection of the vent valve inspection containing 304 SS forging materials plus a variety of select stainless steel specialty parts including some precipitation hardenable and martensitic stainless steels were visually inspected without evidence of any anomalous condition. Additionally, the eight vent valves were actuated to show evidence of sealing while under video inspection.

Although this inspection does not provide positive verification of no intergranular attack, Task 7 believes the quantity of items inspected confirm that intergranular attack and stress cracking was not in evidence at least in an advance state.

- See test results for 18.

3. RCS items continually under the primary coolant:

a. Core Barrel Bolts - A total of 96 bolts machined from Inconel X-750 material and under a nominal stress of 38 KSI were ultrasonically tested. These bolts, too, are representative of another two hundred (approximate) X-750 bolts that are between the SS shells and plates. The results of this inspection showed no evidence of intergranular attack or stress corrosion cracking. The visual examinations in the lower part of the reactor vessel further confirm this conclusion.

- See test results for 12 and 13.

b. RNS Retainer - The RNS retainer assembly made of Inconel X-750 spring material and a number of 304 SS components with weldments was functionally tested (load deflection curves) and destructively examined. The results of this examination concluded the material condition of the assembly was not adversely affected even though some species of sulfur were found to be present on the surface using EDAX methods.

- See test results for 11.

c. Inconel and Stainless Steel Cladding - Penetrant inspections of the lower manway ring and tube sheet sections on both steam generators revealed no evidence of any indication or intergranular cracking. These areas were typically under primary coolant throughout the time when the steam generator was experiencing IGA tube problems on the upper tube sheet. It is again concluded that this environment is not detrimental to cladding.

d. Decay Heat Piping - Ultrasonic and visual testing of decay heat, spent fuel and building spray pipe welds and heat affect zones is already part of our supplemental Section XI Inservice Inspection Testing Program. These results will be completed and available by September.

e. Incore Detectors - An electrical insulation resistance measurement of the 364 rhodium and 52 background incore detectors was performed primarily to determine if a detector's Inconel - 600 sheath was degraded by IGSCC. The recorded high resistance results provide a positive indication of the integrity of both the assembly oversheath and individual detector sheath. This appears consistent with the penetrant inspection results from Test 22.
- See test results from 21.

f. Pressurizer Surge Nozzle - Ultrasonic inspection of safe end material (AS 336 CL FBM) and connecting surge pipe welds (316 SS), including the Inconel 600 buttering pass, indicated that the results do not reveal any evidence of intergranular cracking.
- See test results for 3C.

g. Fuel Assemblies and Control Assemblies - Zircaloy 4 fuel asemblies, 316L stainless steel end fittings, Inconel X-750 hold down springs and Inconel 718 spacer grid assemblies were visually inspected for evidence of intergranular stress corrosion attack or any anomalous material conditions. Three unirradiated and four irradiated fuel assemblies were inspected and all revealed no unusual conditions. These determinations were made by qualified fuels engineers. These engineers are familiar with the appearance and physical conditions of irradiated and unirradiated fuel assemblies.

177 hold down springs were looked at. Only 69 of these springs were partially inaccessible caused by the position of the control elements. No evidence of an IGA or other cracking phenomena was detected.

Two control elements were partially withdrawn to inspect the spider assemblies and other components of interest. Again no sign of IGA or other unusual problems were noted. The conclusion from this data is that IGA or stress cracking is not in evidence visually for components under primary coolant.

From a comparison of the examination data the coolant/air environments that represented the test materials physical location did not exhibit any contrasting conclusions. Each examination confirmed that the tested components were acceptable to the employed testing criteria. All the representative materials that were examined for their susceptibility to IGA by Task 7 showed no evidence of material degradation.

Therefore Task 7's conclusions are:

1. The RCS components were not degraded by the presence of sulfur in the primary coolant system.
2. The RCS components are suitable for service during plant operating conditions.

VII. RECOMMENDATION

The RCS is deemed acceptable for safe operation based on the following:

a. Over 100 hours of video inspection with special emphasis and concentration on sensitized materials, weldments, and heat affect zones revealed nothing that would suggest an intergranular attack with associated stress corrosion cracking. The sensitized materials included a large number of 300 stainless steel and Inconel weldments. While visual examination at 2 to 3X is not considered a sensitive technique to reveal IGA on some tight intergranular cracking, certainly advance states of this phenomena would have been apparent.

b. The metallurgical examinations conducted which included weldments and components with high stress did indicate that no deterioration had taken place either functionally or through viewing the microstructures. This, of course, is considered important input to this recommendation.

c. The ultrasonic and eddy current examination on a number of highly stressed and sensitized materials and/or pressure boundary areas revealed that the RCS materials had not shown any evidence of deterioration. Both of these non-destructive examinations are volumetric examinations and considered reliable indicators for inspecting advanced intergranular cracking of this nature.

d. The penetrant inspection on the cladding, although not a conclusive determinant of the presence of intergranular attack, did reveal that the cladding has integrity and that there are no indications of either cracking or a heavy pitting corrosion attack. The nature of cladding, being a weldment, is such that some minor indications would be considered normal.

The penetrant inspection on the incore detectors which includes weldments and heat affect areas of both inconel and 304 stainless steel, did provide assurance that no intergranular attack was present.

e. The functional tests on the vent valves and incore detectors provides an added level of assurance on the integrity of the functional hardware.

f. The nuclear fuel element inspections again substantiated the recommendation in that no unusual texture in the cladding appearance, the adapters on the space assemblies was noted. One of the unirradiated assemblies did reveal a light straw colored appearance on the fuel rods adjacent to a spacer assembly which was reported, but when this was analyzed chemically, it proved to be normal.

VIII. REFERENCES

1. BAW 1727, TMI-1 Steam Generator Recovery Program, dated April 16, 1982.

2. Three Mile Island-1 OTSG Failure Analysis Report, dated March 15, 1982.

3. Three Mile Island-1 Refueling Operation Procedure 1502-1, TCN 1-82-0039, L-82-0043.

APPENDICES

APPENDIX "A"

GPUN TASK #7

Activity	Individual	GPUN Organization
Task #7 Director	N. Kazanas	Director QA
Asst. Project Engineer	G. Rhedrick	QA Engineer
Asst. Project Engineer	J. Potter	QA Systems Engineer
QA Reviews/Monitoring	D. Langan	Ops QA
Nondestructive Testing	J. Tietjen	Site QC
Nondestructive Testing	M. Hipple	Site QC
Nondestructive Testing	D. Jackson	Contracted N.E.S.
Nondestructive Testing	W. Kimmick	Site QC
Nondestructive Testing	R. Ostrowski	Material Technology
Nondestructive Testing	G. Oswald	Site QC
Nondestructive Testing	R. Turner	Material Technology
Nondestructive Testing	M. Zeise	Material Technology
Mechanical Maint. Super.	M. Feary	Maintenance Foreman
Mechanical Maint. Super.	R. Natale	Maintenance Foreman
Fuel/Core Inspection	G. Bond	Nuclear Analysis & Fuel Director
Fuel/Core Inspection	S. Wilkerson	TMI Lead Nuclear Fuel Engineer
Fuel/Core Inspection	J. Strair	TMI Nuclear Fuel Engineer
Fuel/Core Inspection	C. B. Mehta	TMI Fuels Project
Fuel/Core Inspection	D. Shoua	TMI Fuels Project
Fuel/Core Inspection	R. M. Rama	TMI Fuels Project
Fuel/Core Inspection	J. McCarthy	Engineer TMI Fuels Project
Maintenance Coordination	R. Harper	Maintenance/Construction Manager
Task #7 Field Coordinator	H. Wilson	Preventive Maintenance Supervisor

Activity	Individual	GPUN Organization
Operations Coordination	M. Ross	Manager Plant Ops Unit I
Operations Coordination	H. Shipman	Ops Engineer Unit I
Destructive Testing	S. Giacobbe	Welding & Material Manager
Destructive Testing	R. Miller	Metallurgist
I&C Support	M. Toole	Maintenance Supervisor
Scheduling	D. Reil	Manager M&C Planning
Scheduling	J. Hawkins	M&C Job Order Planner
Scheduling	J. Rudelle	M&C Job Order Planner
Radiological Coordinator	D. Ethridge	Radiological Engineer
Radiological Coordinator	J. Kuehn	Deputy Manager Rad Con

APPENDIX "B"

B&W TASK 7

Name	Activity	B&W Organization
W.H. Abbott	Inspection Report	Engineering Department
R.C. Ballou	On-Site RV Inspection	Engineering Department
D.L. Baty	O-Ring & CDRM Closure Exam	Lynchburg Research Center
H.W. Behnke	Task Leader and On-Site RV Inspection	Engineering Department
D.N. Bryant	On-Site NDE	Special Products & Inspection Services
C.G. Dideon	Fuels Coordination	Engineering Department
J.C. Dillard	O-Ring & CDRM Closure Exam	Lynchburg Research Center
V.D. Downs	O-Ring & CDRM Closure Exam	Lynchburg Research Center
F.R. Faist	On-Site Resident Engineer	Field Services
D.F. Ferree	NDE Development	Special Products & Inspection Services
W.T. Hamilton	O-Ring & CDRM Closure Exam	Lynchburg Research Center
R.W. Laughlin	On-Site NDE	Special Products & Inspection Services
J.E. Matheson	On-Site New Fuel Inspection	Engineering Department
J.T. Mayer	On-Site Irradiated Fuel Inspection	Lynchburg Research Center
W.A. McInteer	RNS Retainer Inspection - Hot Cell	Lynchburg Research Center
B.J. Parham	O-Ring & CDRM Closure Exam	Lynchburg Research Center
R.S. Piascik	Materials Engineer	Engineering Department
J.B. Woodward	On-Site Video	Special Products & Inspection Services

APPENDIX C

Examination Results and Validation

1. OTSG stainless clad upper and lower head & 2. OTSG inconel clad upper and lower tube sheet	Dye penetrant and wipe samples of the upper and lower tube sheet and upper and lower head
3A. Make up nozzle safe end, B. HPI nozzle safe ends, C. spray line pressurizer nozzle safe end, surge line pressurizer nozzle safe end	(3A) Dye Penetrant: Muv-95, Muv-86-A and 86-B, Visual: Muv-94, Muv-95, Muv-86A and Muv-86B, Radiography: Muv-94, Muv-95, Muv-86A, Muv-86B Ultrasonic: Muv-94, Muv-95, Muv-86A and Muv-86B (3B) Radiography: Pressurizer spray nozzle, Ultrasonic - pressurizer spray nozzle (3C) Ultrasonic - pressurizer surge nozzle
4. Lead screw	Results reported by Failure Analysis Group (Task - 1)
5. Reactor vessel inner o-ring	Laboratory metallographic investigation site and B&W LRC
6. Motor tube	Ultrasonic examination of motor tube #63, 66 and 68.
7. CRDM end fitting	Laboratory metallography investigation.
8. Hold down bolts of plenum lift lugs	Ultrasonic examination of (6) plenum lifting lugs.
9. Top of core and control component	Visual examination of report.
10A. Fuel assembly & B. control component C. reactor internals D. baffle plate region	(10A) Visual examination of un-irradiated fuel (10B) Visual examination of irradiated fuel (10C) Visual examination of baffle region & RV internals (10D) Visual examination of control component
11. RNS retainer	Laboratory metallographic investigation.
12. Core support shield to core barrel bolt	Ultrasonic examination of bolts.
13. & 14. Lower bolting rings in RV internals and lower vessel head	Visual examination of RV internals.

Appendix C (cont'd)
Examination Results and Validation

15.	CRDM nozzles to stainless flange	Eddy current examination of motor tube #68.
16.	Plenum assembly	Visual examination of structural components.
17.	Plenum cylinder to plenum cover bolts	Ultrasonic examination of bolts.
18.	Vent valves and core support shield I.D.	Visual and functional examination of valves and structural components.
19.	Intentionally left blank	Deleted inspection.
20.	Low pressure injection pipe welds	Re-scheduled for supplementary ISI
21.	Incore detectors	Functional exam.
22.	Incore detector sheath	Dye penetrant exam and wipe samples B&W analysis.
23.	Vent valve thermocouple nozzle	Eddy current exam of nozzles