SG-83-08-008

WCAP-10268

MILLSTONE UNIT 2
STEAM GENERATOR SLEEVING REPORT

Prepared for Northeast Utilities
Service Company

July, 1983

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1.0 INTRODUCTION

As part of its ongoing steam generator repair programs, Westinghouse has developed the capability to repair degraded steam generator tubes by means of a sleeve. This technology will be applied to the steam generators of Millstone Unit 2 with the objective of effecting a repair to such tubes.

Millstone Unit 2 is a pressurized water reactor rated at 2700 MWt, designed by Combustion Engineering (CE). The unit utilizes two vertical U-tube steam generators, each with 8519 heat transfer tubes with dimensions of 0.750 inch OD by 0.048 inch wall thickness. Previous experience by Westinghouse in sleeving steam generators at San Onofre 1, Indian Point 3, and Point Beach 1 has been drawn upon to optimize procedures and parameters for use at Millstone 2 so that the integrity of the reactor coolant system pressure boundary is not compromised by the installation of sleeves.

The Westinghouse effort described in this report will be accomplished in accordance with WCAP-9245, Rev. 6, June 1982, "Quality Assurance Program Plan". This Plan complies with the NRC Quality Assurance criteria, 10 CFR 50 App. B, and follows the regulatory positions provided in associated NRC Regulatory Guides. The Plan is also consistent with ANSI standards and ASME Code Requirements.

The sleeving concept and design are based on observations to date that the tube degradation due to pitting attack has occurred in both the hot and cold legs of the tube bundle, confined to a height of approximately one foot above the top of the tubesheet. The sleeve has been designed to span these degraded regions of tubes in order to maintain these tubes in service. This report presents a discussion of the design criteria, process description, tooling utilized, inspectability, and ALARA considerations concerning the application of the sleeving concept.

2.0 SLEEVING OBJECTIVE AND BOUNDARIES

2.1 OBJECTIVES

The sleeving program has two primary objectives:

1. To sleeve tubes in the region of tube degradation

2. To minimize the radiation exposure to all working personnel (ALARA)

At the San Onofre Unit 1 Plant of Southern California Edison Co., more than 6,400 degraded tubes (including leakers) were sleeved, tested and returned to ser- vice using remote X-Y installation equipment developed by Westinghouse. After this project, the tooling was redesigned, implementing experience from the field to provide additional reliability, maintainability, and ease of installation. The resultant remote sleeving system was adapted to a Westinghouse Model 44 series steam generator and utilized in the sleeving operations at Indian Point 3 and at Point Beach 2. Process modifications were successfully employed during the installation of 13 demonstration sleeves in a hands-on mode at the Point Beach Unit 1. To date, more than 12,000 sleeves have been successfully installed utilizing both remote and hands-on tooling. All modifications to the remote sleeving system have emphasized the objective of minimizing the amount of time required for channel head workers to be exposed to the radiation field. This sleeving system will be modified to perform under the field conditions of the CE steam generators at Millstone 2.

2.2 SLEEVING BOUNDARY

Tubes to be sleeved will be selected by location in the tubesheet, tooling access, and eddy current indication elevation and size. Additionally, an axial elevation tolerance of 1 inch is being employed to allow for eddy current testing position indication inaccuracies. Sleeve length, tube location in the tubesheet, and tooling access define the sleeving boundary. Figure 2.2-1 shows the sleeving boundary as determined by the channel head inside surface-to-tubesheet primary face clearance distance minus the maximum tooling clearance distance. This information along with eddy current

inspection data provides the inputs utilized to evaluate each tube for the repair process. Table 2.2-1 gives the reference sleeving boundary for the number of tubes qualifying. The remote sleeving system will be used to install [ ]a,c,e sleeves within the sleeving boundary. Also, there will be a number of [ ]a,c,e sleeves inserted by the hands-on method due to tooling and/or existing tube plug interference. It is estimated that the hands-on method will be used on less than 25 percent of the total number of tubes to be sleeved.

The specific tubes in each steam generator to be sleeved with a [ ]a,c,e mechanical sleeve or to be plugged will be identified once eddy current inspection results have been analyzed and the following variables have been determined:

1. Tube conditions which exist outside of the sleeving boundary which may preclude sleeving and may be removed from service.

2. Final determination of those tubes to be sleeved by the remote sleeving system or the hands-on mode, based on ALARA considerations to maximize the use of the automatic remote methods and minimize radiation exposure.

Tubes that are degraded beyond the plugging limit but not within the sleeving region will be plugged.

TABLE 2.2-1

NUMBER OF CANDIDATE TUBES WITHIN REFERENCE SLEEVING BOUNDARY

	STEAM GENERATOR 1	2	Total
Total Candidate Tubes for Sleeving	1500⁺	1500⁺	3000⁺
Existing Plugs	784	723	1507
Non-Sleevable Tubes⁺⁺	(TBD)	(TBD)	(TBD)
Total Tubes in Steam Generator(s)	8519	8519	17038

\+ Preliminary Values

++ Defined as tubes that are not plugged but are outside the sleeving region due to tooling access or are not sleevable due to eddy current indication elevation.

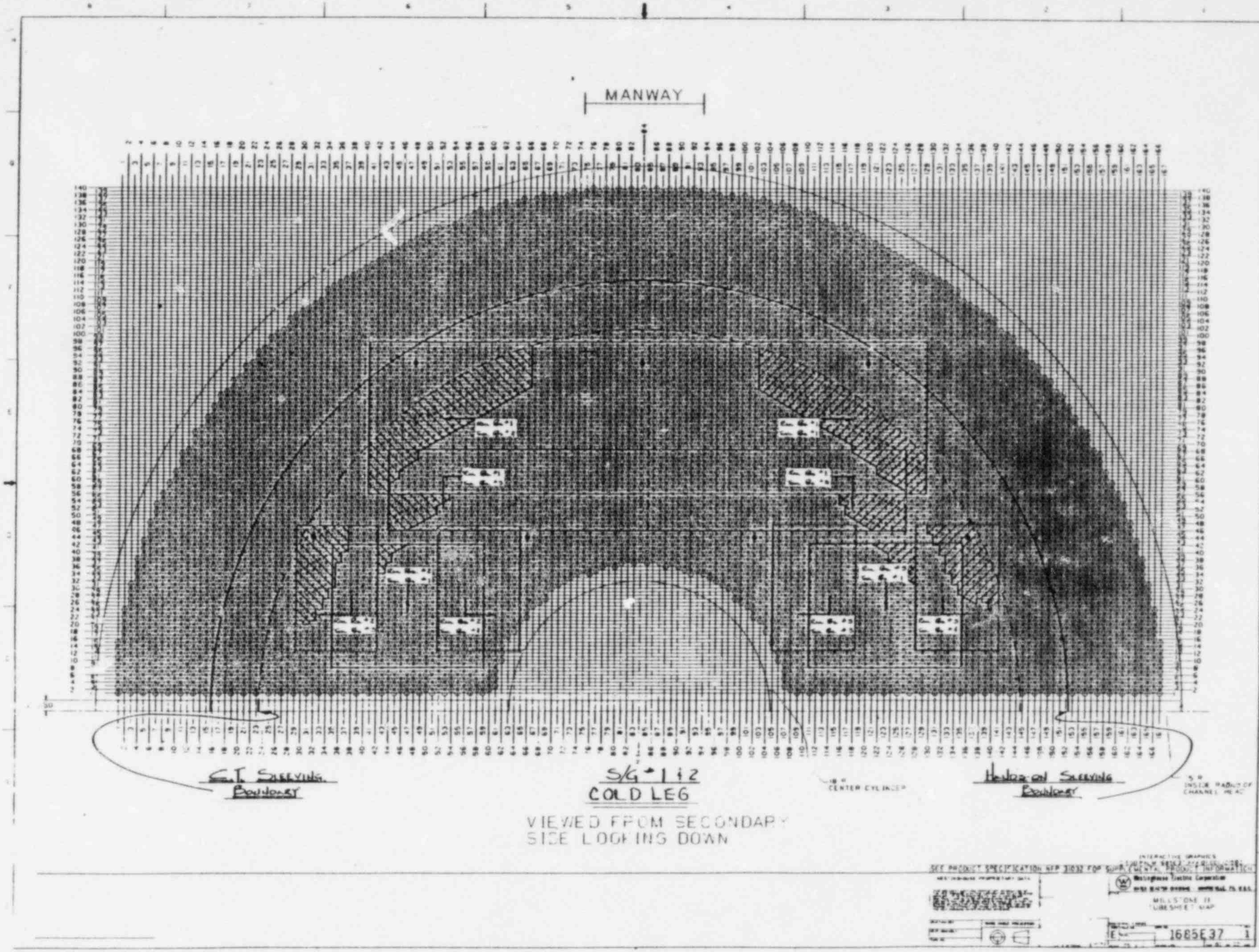


FIGURE 2.2-1 SLEEVING BOUNDARY

3.0 DESIGN

3.1 SLEEVE DESIGN CRITERIA

Although the original Millstone Unit 2 steam generators were built to the 1968 edition of Section III of the ASME Boiler and Pressure Vessel Code, the sleeves have been designed and analyzed to the 1980 edition of Section III of the Code through winter 1980 Addenda as well as applicable Regulatory Guides. The associated materials and processes also meet the requirements of the Code. Table 3.1-1 presents the specific requirements addressed.

Other criteria used in the design include the capability of the sleeve to accommodate field conditions which may be experienced, including variable tube end conditions and nonparallel, nonstraight, and dented tubes.

Variations in the condition of the tube end consist of tube wall thickness variations, variations in the ID at the weld, ovality variations of the tube diameter, and amount of expansion below the tubesheet surface. Areas of the sleeve design and process upon which these conditions impact include maximum and minimum permissible sleeve diameters, installation of the sleeve, and the joining of the lower end of the sleeve to the original tube. Nonparallel and nonperpendicular conditions may be the result of tubesheet drilling variations or support grid alignment tolerances, and are considered in the sleeve diameter selection. Additionally, the sleeving process must be capable of preparing the oxidized condition of the tubing inner surfaces to be suitable for hydraulically expanded and roll expanded joints.

In addition to addressing Code and Regulatory requirements and field conditions, additional objectives or criteria are imposed. These include:

- Preclude introducing adverse effects on the pressure-retaining capability in the remaining tube above the upper joint.

- Place the upper joint at an elevation to provide a section of unstressed, undeformed sleeve above the upper joints to prevent a double-ended break condition of the tube.

- Design a structurally adequate sleeve for fatigue considerations based on ASME Code fatigue analysis for a projected operating period of 35 years.

- Select sleeve material for additional corrosion resistance.

- Size sleeve to minimize sleeve/tube interactions and loading on the upper joint.

- Permit inspectability of the sleeve and upper joint.

- Provide for remote sleeve installation.

- Design for hands-on installation

- Minimize increase to primary flow resistance.

- Minimize effects of the sleeving processes on the tube-to-tubesheet weld.

- Consider location of tube degradation above secondary side of tubesheet.

3.2 SLEEVE DESIGN DESCRIPTION

The reference design of the sleeve, as installed, is illustrated in Figure 3.2-1 [

]a,c,e

[

]a,c,e The combination of hydraulic and mechanical expansion at the sleeve upper end is called the hybrid expansion joint (HEJ).

The sleeve is manufactured with a slight bow over its length, except for the ends where the sleeve-to-tube joints will be made. This bow, approximately 0.080 inch at the midspan, is provided to cause a light lateral contact force between the sleeve and tube upon insertion. This keeps the sleeve in place between being inserted by the Cartridge Sleeve Loader (see Section 5.3) and being hydraulically expanded as part of the upper and lower joints formation. The sleeve-to-tube lateral contact occurs approximately 1 inch below the top of the tubesheet.

Section 6 of this report presents the sleeve design verification. Section 6.1 describes the verification test program. Sections 6.2 and 6.3 present the analytical verification and special considerations, respectively.

At the upper end, the sleeve configuration (shown in Figure 3.2-1) consists of a section [ ]a,c,e into the original tube, and a section between [

]a,c,e

At the lower end, the sleeve configuration (shown in Figure 3.2-2) consists of a section [

]a,c,e This range of wall thinning has been established through laboratory testing as the range which is

effective in terms of leak-tightness, mechanical strength, and adequate resistance to stress corrosion cracking.

The determination of the various sleeve dimensions is largely controlled by the field conditions of the existing tubes as discussed in the previous section. The sleeve extends above the top of the tubesheet and spans the degraded area of the tubes. The sleeve is made as long as possible within the restrictions of insertion clearance between the channel head inside surface and the primary side of the tubesheet. The [

]^{a,c,e} The remaining design parameters such as wall thickness and material were selected to enhance design margins and corrosion resistance or to meet ASME Boiler and Pressure Vessel code requirements. The upper joint is located to provide a length of free sleeve above it. This length is added so that if the existing tube were to become severed just above the upper edge of the roll expansion, the tube would be restrained by the sleeve and therefore axial motion, and subsequent leakage, would be limited. Lateral motion would also be restricted and adjacent tubes protected from impacting by the severed tube.

To minimize stress concentrations and to permit inspectability in the area of the upper expanded region, [

]^{a,c,e,f}

The sleeve material is also an important factor in providing design margin. Thermally treated Alloy 625/690 bimetallic sleeving has been selected to provide additional resistance to pitting and maintain resistance to stress corrosion cracking and general corrosion. (See Section 6.1.2.3 for further details of the selection of thermally treated Alloy 625/690 bimetallic material).

TABLE 3.1-1

ASME CODE AND REGULATORY REQUIREMENTS

Item	Applicable Criteria	Requirement
Sleeve Design	Section III	NB-3200, Analysis NB-3300, Sizing Test
	Operating Requirements per Appendix B of this Report	Analysis Conditions
	Reg. Guide 1.83	S/G Tubing Inspectibility
	Reg. Guide 1.121	Plugging Margin
Sleeve Material	Section II	Material Composition
	Section III	NB-2000, Identification, Tests and Examinations
	Code Case N-379	Mechanical and Chemical Properties, Marking
Sleeve Joint	10CFR100	Plant Total Primary-Secondary Leak Rate
	Technical Specifications	Plant Leak Rate

a, c, e, f

Figure 3.2-1 Hybrid Expansion Upper Joint/Roll Expanded Lower Joint Sleeve Configuration

a, c, e, f

Figure 3.2-2 Sleeve Configuration Lower End

4.0 PROCESS DESCRIPTION

The actual sleeve installation consists of a series of steps starting with tube end preparation (contingency) and progressing through sleeve insertion, hydraulic expansion at both the lower joint and upper hybrid expansion joint (HEJ) regions, hard roll expansions at both joint locations, and joint inspection. The steps are essentially the same for both automatic operation and for hands-on operation. The installation sequence is outlined in Table 4.1-1 and is shown schematically on Figure 4.1-1. All these steps are described in the following sections.

The process steps are accomplished by a manufacturing sequence which defines the overall progression of operations on a lot basis. Lot size varies from 50 to 200 tubes depending on the quantity of tubes that can be reached with a single setting of the remote sleeving system rail/tool position or how many tubes can be worked in the hands-on mode on a per-shift basis.

4.1 TUBE PREPARATION

There are two steps involved in preparing the steam generator tubes for the sleeving operation. These consist of tube honing and light rolling (as required) of the tube end.

4.1.1 TUBE HONING

The sleeving process includes honing the ID of tubes to be sleeved to prepare the tube surface for the lower joint and the upper hybrid expansion joint by removing loose oxide and foreign material.

Tube honing will be accomplished using the remote sleeving system employing a [

]a,c,e

[

][a,c,e] (Note: hands-on or manual honing will be performed with the same system.)

A limit switch is included in the system which prevents the drive from reversing direction until the desired length of the tube has been honed.

A waste handling system is used to collect the rinse water, the hone debris and the oxide film removed from the tube ID. [

][a,c,e] There is also an inlet to the suction pump which subsequently pumps the debris and water to the plant waste disposal system.

In order to verify that tube ID surfaces have been honed, a fiberscope inspection will be performed on a minimum of 10 percent of the tubes to be sleeved. Tubes to be fiberscope inspected will be selected randomly throughout the actual honing sequence. The fiberscope inspection will be accomplished prior to sleeve insertion.

The honing process removes loose particles from the ID surfaces of the tube ends and provides some benefit by reducing radiation shine.

The presence of a honed pattern on the tube ID surfaces in the honing region indicates an acceptably honed tube. A honed pattern is any difference in surface texture between the honing region and the remainder of the tube.

If it is determined that honing has not been satisfactorily performed on one or more tubes in a steam generator, additional fiberscope inspection will be performed on randomly selected tubes throughout the honing sequence, concentrating on tubes honed near in the sequence to the identified non-honed tube(s). All tubes determined as not satisfactorily honed will be re-honed and reinspected until it has been determined that honing has been performed.

4.1.2 TUBE END ROLLING

If necessary in order to provide a uniform tube opening for sleeve insertion, a light mechanical rolling operation [ ]a,c,e will be performed. This is sufficient to prepare the mouth of the tube for sleeve insertion without adversely affecting the original tube-to-tubesheet weld. The higher torque will be used only in cases of severely restricted tube end welds. Unless gaging or tube inside diameter measurements indicate a need, tube end rolling will be performed only as a contingency.

Tests performed by Northeast Utilities in preparation for installation of mechanical plugs in February of 1982 indicated that the tube-to-tubesheet weld roll-over could be expanded by mechanical rolling to make the weld flush with the tube ID. No damage to the weld was apparent. A total of 1410 mechanical plugs were installed after the welds had been rolled flush with the tube ID.

4.2 SLEEVE INSERTION AND EXPANSION

In the process of sleeving the tubes, a mandrel (Figure 4.2-1) carrying high pressure demineralized reactor service grade water is used to expand regions of the inserted sleeves into contact with the existing tubes in the steam generator. The following paragraphs describe the installation of the sleeves and mandrels and the hydraulic expansion of the sleeves at both the lower joint and upper HEJ locations.

The manufactured sleeves are fabricated under controlled conditions, machined, cleaned, and inspected. The sleeves are then placed in plastic sleeves, plugged at each end with plastic plugs, individually placed in plastic bags, and packaged in protective styrofoam trays in boxes. The boxed sleeves are carried (one box at a time) to a low radiation, controlled region within the containment near the steam generator. Here, the sealed sleeve box is opened.

Depending on the mode of sleeve insertion, Cartridge Sleeve Loader, Sleeve/Mandrel Insertion Tool, or hands-on, the process involves either loading expansion mandrels into sleeves or loading sleeves in the cartridge that is placed in the cartridge sleeve loader.

4.2.1 AUTOMATIC SLEEVE INSERTION

For the sleeve/mandrel insertion tool mode of sleeve insertion, the first step involves the mandrel/sleeve loading process. In the mandrel/sleeve loading process, a sleeve is removed from the sleeve box. [ ] a,b,c,e

a,b,c,e

[ ]

In the event a sleeve becomes stuck after only partial insertion, contingency methods and tooling are used to remove the stuck sleeve. The tube will then be dispositioned by way of a non-conformance report after considering the appropriate input.

4.2.2 AUTOMATIC SLEEVE EXPANSION

Automatic sleeve expansion is performed in one of the following described manners dependent on whether sleeve insertion was performed by the Cartridge Sleeve Loader or the Sleeve/Mandrel Insertion Tool. If the Sleeve/Mandrel Insertion Tool is used as the primary means of insertion, the expansion of the sleeve is performed after each individual insertion.

In the case where the Cartridge Sleeve Loader is the primary means of sleeve a,b,c,e

[ ]

In either mode of expansion, the system is pressurized to approximately [ ]a,c,e with demineralized (reactor service grade) water. This expands the sleeve radially so that the upper and lower expansion regions are in contact with the steam generator tube and so that in the upper joint region, the tube expands diametrically by approximately [ ]a,c,e.

The expansion pressure is controlled so that the upper HEJ expansion produces the tube expansion desired. The expansion pressure is then relieved and the mandrel is extracted from the tube.

4.2.3 HANDS-ON MANDREL/SLEEVE INSERTION AND EXPANSION

a, b, c, e

In both the automatic and the hands-on processes, the procedures are repeated until all necessary sleeves have been loaded and expanded.

4.3 LOWER JOINT SEAL

At the primary face of the tubesheet, the sleeve and tube will be joined into an essentially leaktight pressure boundary. The method chosen for this operation is a mechanical hard roll (following the hydraulic expansion) performed

with a hydraulic or air-driven roll expander which extends approximately [ ]^{a,c,e} inches into the tube. The control of the mechanical expansion is maintained through a torque setting or time limit. The tool automatically shuts off either when it reaches a preset torque value or after running for a preset time. This joint can be quickly formed and easily inspected, thus minimizing worker time in the channel head.

The contact forces between the sleeve and tube due to the initial hydraulic expansion are sufficient to keep the sleeve from rotating during the roll expansion process. The hydraulic expansion step also helps minimize the magnitude of the residual stresses of the final joint configuration.

The correct amount of expansion of the sleeve is accomplished by controlling the applied torque during rolling. The hard roller torque is calibrated on a standard Torque Calibrator prior to initial hard rolling operations and subsequently recalibrated at the beginning of each shift for automatic tooling and approximately every 4 hours for hands-on equipment. This control and calibration process is a proven technique used throughout industry in the installation of tubes in heat exchangers.

4.4 UPPER HYBRID EXPANSION JOINT (HEJ)

The HEJ first utilizes a hydraulic expansion zone of [

]^{a,c,e} In the automatic mode, a hard roller is attached to the CTM which positions it beneath an inserted and hydraulically expanded sleeve. The hard roller is then inserted into the sleeve until it is positioned at the prescribed axial location. The hard roller is then operated for approximately [ ]^{a,c,e} seconds. At the end of this time the roller will have expanded to its set diameter and the total tube expansion of approximately [ ]^{a,c,e} inch diametral will have occurred. The maximum torque of the hydraulic or air operated drive motor is set at a value of approximately [ ]^{a,c,e} which is sufficient to achieve the desired tube expansion.

In the hands-on mode, a worker enters the channel head. The worker is handed a hard roller and a torque gun. The worker then inserts the hard roller into a prescribed sleeve. The torque gun is actuated for approximately [ ]^{a,c,e} seconds to make the roll joint. After the joint is rolled, the hard roller is moved to the next prescribed sleeve and the hard roll process is repeated.

One of the sleeve length optimization guidelines was that the lowermost elevation of the HEJ roll expanded region be positioned a minimum of 1 inch above the eddy current detected degraded area of the tube. Since the degradation at Millstone 2 is within approximately one foot of the top of the tubesheet, selection of the [ ]^{a,c,e} sleeve length was made so that this one inch buffer zone is maintained.

4.5 PROCESS INSPECTION SAMPLING PLAN

In order to verify the final sleeve installation, an eddy current inspection will be performed on all sleeved tubes to verify that all sleeves received the required hydraulic and roll expansions. The basic process checks on 100 percent of the sleeved tubes will be:

(1) Verify lower hydraulic expansion average diameter
(2) Verify lower roll and location within the lower hydraulic expansion and average diameter
(3) Verify upper hydraulic expansion average diameter
(4) Verify upper roll elevation and location within the upper hydraulic expansion and average diameter.

Tubes not satisfying the basic process check criteria will be dispositioned on a tube-by-tube basis.

In order to monitor the sleeving process after each operation from each lot, eddy current data on a percentage of the sleeves will be performed to obtain sleeve ID data. As confidence is gained that the sleeving process is proceeding as anticipated, the lot sizes will be increased and percentages reduced. These average diameters will be evaluated versus the expected tolerances established through the design requirements, laboratory testing results, and

previous experience. This evaluation will determine that the equipment/tooling is performing satisfactorily. If process data is determined to be outside of expected ranges, further analysis will be performed.

If required, Diatest may be used in lieu of eddy current to perform sleeve installation acceptance and in-process monitoring evaluations. Undersized diameters are corrected by an additional expansion step to produce the desired degree of expansion. Oversized diameters will be dispositioned by a specific evaluation process on a tube-by-tube basis.

If, judged by an evaluation of a specific sleeve/tube configuration, it is necessary to remove a sleeved tube from service, the lower portion of the sleeve will be removed and the tube will be plugged.

4.6 SLEEVING PROCESS COMPARISON

A considerable amount of actual field experience has been obtained installing sleeves in tubes at San Onofre Unit 1 (SCE), Indian Point Unit 3 (INT), and Point Beach Unit 2 (WIS). This experience plus the process limited scope and verification test programs conducted for Millstone Unit 2 (See Section 6) form the basis for the process parameters selected for the installation of sleeves in the Millstone Unit 2 steam generators. While the overall processes are very similar in all of these programs, certain differences exist due to modifications in sleeve design and/or different tube dimensions. Table 4.6-1 gives a comparison of many of the parameters used for each plant.

TABLE 4.1-1

SLEEVE PROCESS SEQUENCE SUMMARY

a,b,c,e

TUBE PREPARATION	1)	
	2)	
	3)	
SLEEVE INSERTION	4)	
	5)	
	6)	
	7)	
LOWER JOINT FORMATION	8)	
UPPER JOINT FORMATION	9)	
INSPECTION (Process Verification)	10)	

TABLE 4.6-1 (Page 1 of 4)

SCE/INT/WIS VS. MILLSTONE 2 SLEEVING PROCESS COMPARISON - TUBE PREPARATION

	PROCESS COMPARISON			
	SCE	INT/WIS	MILLSTONE 2	SIGNIFICANCE
TUBE DIMENSIONS	0.750 in. OD x 0.055 in. wall	0.875 in. OD x 0.050 in. wall	0.750 in. OD x 0.048 in. wall	None
SLEEVE DIMENSIONS			a,c,e	None
PROCESS				
HONING				No Change
LIGHT ROLL AXIAL LENGTH*				Provides Uniform Tube Opening for Sleeving Insertion
LIGHT ROLL TORQUE*				No Effect on Lower Joint. Torque to allow for opening of more restricting welds.
LIGHT ROLL DIAMETER*				No Effect on Lower Joint

*Contingency

TABLE 4.6-1 (Page 2 of 4)

SCE/INT/WIS VS. MILLSTONE 2 SLEEVING PROCESS COMPARISON - HYDRAULIC EXPANSION UPPER AND LOWER JOINTS

PROCESS	PROCESS COMPARISON SCE	INT/WIS	MILLSTONE 2	a,c,e	SIGNIFICANCE
INITIAL DIAMETRAL CLEARANCE					None
EXPANSION ZONE AXIAL LENGTHS (NOMINAL)					No Change
					No Change
PRESSURE					No Significant Effect - Actual pressure established based on tube expansion diametral bulge

TABLE 4.6-1 (Page 3 of 4)

SCE/INT/WIS VS. MILLSTONE SLEEVING PROCESS COMPARISON - LOWER END HARD ROLL

PROCESS COMPARISON

a,c,e

PROCESS	SCE	INT/WIS	MILLSTONE 2	SIGNIFICANCE
LENGTH				Range due to full depth expansion of the original tube in the tubesheet. No transition zone in original tube in this region.
WALL REDUCTION				No significant effect change based on test data
ROLL EXPANSION TORQUE				No Significant Effect Change Due to Decreased Sleeve Diameter and Increased Material Strength.
NO. ROLLERS				No Change

TABLE 4.6-1 (Page 4 of 4)

SCE/INT/WIS VS. MILLSTONE 2 SLEEVING PROCESS COMPARISON - UPPER JOINT HARD ROLL

PROCESS COMPARISON

a,c,e

.ROCESS	SCE	INT/WIS	MILLSTONE 2	SIGNIFICANCE
LENGTH				No Significant Change
ROLL EXPANSION TORQUE				Sufficient torque to prevent "torque-out".
MAX. DIAMETRAL EXPANSION				No Significant Change
NO. ROLLERS				No Change

a,c,e,f

FIGURE 4.1-1 HEJ SLEEVE PROCESS

a,c,e

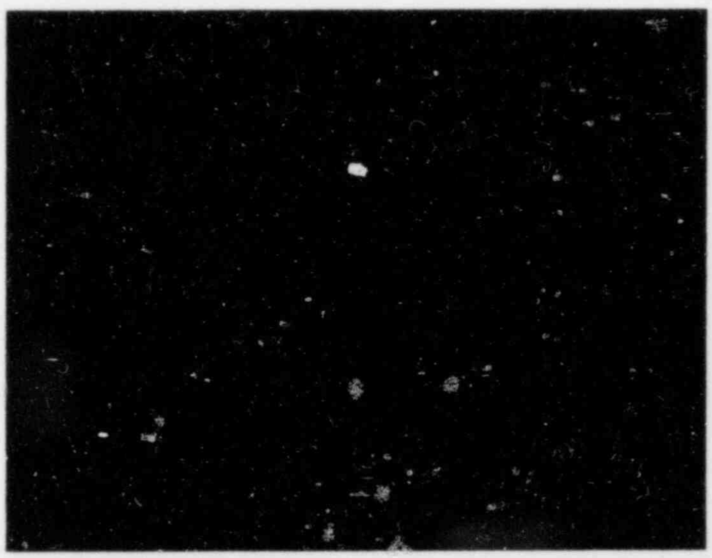


Figure 4.1-2. Tube Hone

5.0 REMOTE INSTALLATION EQUIPMENT

Tooling has been designed to perform the sleeving processes described in Section 4.0 while being operated and controlled from a remote control station outside of containment. The sequence of operation for each remote tool is explained below.

5.1 COORDINATE TRANSPORTER MACHINE (CTM)

The CTM (Figure 5.1-1) has been developed to position sleeving tools for Westinghouse steam generators and for the Millstone 2 CE steam generators. After the tools are positioned at the desired tube location, [

]a,c,e The CTM position is verified by reading the tube numbers off the previously installed tubesheet template.

The CTM positioning unit consists of the following subassemblies:

1. [ ]a,c,e

2. [ ]a,c,e

3. [ ]a,c,e

4. [

]a,c,e

5. [

]a,c,f

In operation, the system is set up in the following manner:

1. [

2.

3.

4.

5.

]a,c,e

The system is used in the following manner:

1. [

2.

3.

4.

5.

6.

]a,c,e

5.2 SLEEVE/MANDREL INSERTION TOOL

The tool fits through the steam generator manway and attaches to the coupler portion of the channel head CTM. The tool is controlled remotely. The sequence of operations for the tool is as follows:

1. [

2.

3.]a,c,e

4. [

5.

6.

7.

8.

9.

]a,c,e

5.3 CARTRIDGE SLEEVE LOADER

This tool is an end effector which fits through the steam generator manway and attaches to the coupler portion of the CTM. This tool was designed to be used in conjunction with the previously described sleeve insertion and expansion tool in order to minimize man-rem exposure. The tool is controlled remotely. The sequence of operations for the tool is as follows:

a, c, e

[ ]

a,c,e

a, c, e, f

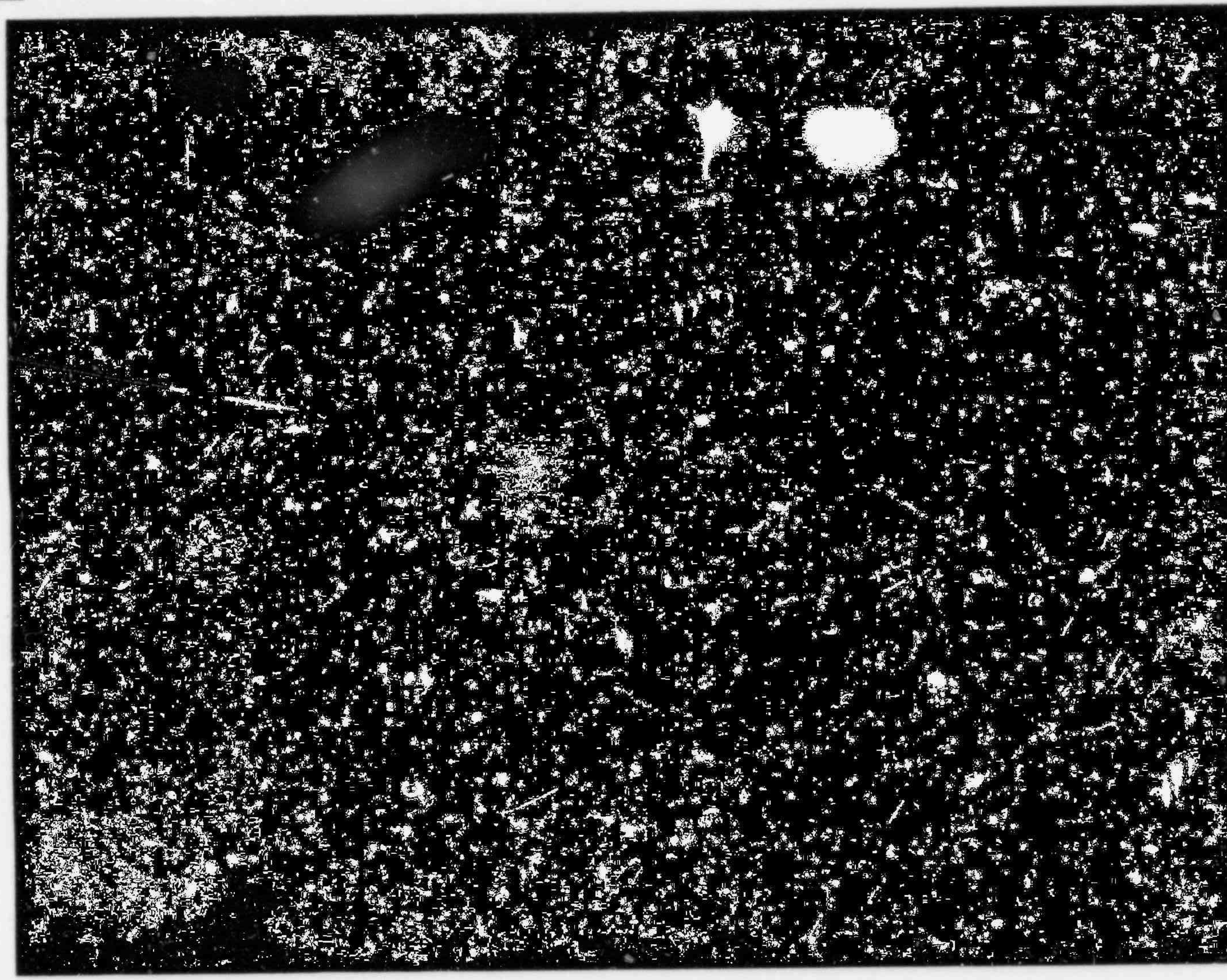


Figure 5.1-1. Coordinate Transport Machine (CTM) Typical

4734-6

6.0 DESIGN VERIFICATION: TEST PROGRAM AND STRESS ANALYSIS

6.1 INSTALLATION PROCESS AND DESIGN VERIFICATION TEST PROGRAM

The following sections describe the installation process and design verification test program. The purpose of this test program is to verify the ability of the sleeve installation process to produce a sleeve capable of spanning a degraded region in a steam generator tube and maintaining the steam generator tubing primary-to-secondary pressure boundary under normal and accident conditions. This includes assessment of the structural integrity and corrosion resistance of sleeved tubes. Table 6.1-9 identifies the main issues addressed by the mechanical test program.

6.1.1 SLEEVING TEST PROGRAM SUMMARY

A substantial data base exists from tests which verified the sleeve design adequacy of the sleeving programs performed at San Onofre, Point Beach, and Indian Point. Much of the testing is applicable to the Millstone Unit No. 2 sleeving program. The fabrication of sleeve/tube joints by the combination of hydraulic expansion and roll expansion at both ends of the sleeve was verified and applied during these previous sleeving programs. The mechanical verification testing program is described in Table 6.1-10. The sleeving materials used for the San Onofre, Point Beach, and Indian Point sleeving activities was thermally treated Inconel Alloy 600. The sleeving material for Millstone Unit No. 2 is a bimetallic, composed of an outer layer of Inconel Alloy 625 and an inner pressure retaining layer of Inconel Alloy 690. The Inconel Alloy 625 was selected based on its improved pitting resistance while the Inconel Alloy 690 was selected to provide excellent corrosion and SCC resistance under both primary and secondary-side conditions.

For Millstone Unit 2, an extensive verification program has been conducted to demonstrate the adequacy of the sleeve design including material selection. The objectives of the material and corrosion program were:

A. Demonstrate by appropriate NDE and metallographic methods that the bimetallic sleeving material meets all of the ASME Boiler and Pressure

Vessel Code, Section II and Section III (1980 Edition through Winter 1980 Addenda), and Code Case No. 379 requirements.

B. Verify that the sleeving manufacture and field installation processes do not introduce any conditions which would result in premature tube or sleeve degradation.

C. Verify that the bimetallic sleeving provides bit initiation resistance along with acceptable resistance to other modes of corrosion. (All results to be compared with mill annealed Inconel Alloy 600 performance).

6.1.2 CORROSION AND MATERIAL PROGRAM

The material and corrosion verification program consisted of the following principal tasks:

A. Screening Tests For Pitting Resistant Material
B. Bimetallic Sleeve Manufacture
C. Metallurgical Characterization
D. Corrosion Evaluation

6.1.2.1 SCREENING TESTS FOR PITTING RESISTANT MATERIAL

The outer bimetallic sleeve material is to possess a demonstrated resistance to pitting corrosion, while the total wall is to exhibit resistance to stress corrosion cracking (SCC), intergranular attack (IGA), and general dissolution (GDC) or "wastage" (thinning). Chlorides, particularly acid chlorides, are the principal promoters of pitting in the alloy families which are acceptable for sleeving applications.

In order to evaluate the candidate Millstone Unit No. 2 sleeving materials, a series of standard or conventional pitting immersion tests, along with a series of immersion tests in simulated off-chemistry steam generator environments were performed. These tests were designed to evaluate the pitting resistance of candidate Millstone Unit No. 2 sleeving alloys.

A series of immersions tests at 125°F, 180°F, and 520°F, using various candidate sleeving alloys, were performed to select a pitting resistant alloy which could be used as a outer clad with Inconel Alloy 690. Composition of candidate outer sleeve materials evaluated for bimetallic usage are listed in Table 6.1-1. The environments evaluated are listed in Table 6.1-2. [

]b,c,e

6.1.2.2 Bimetallic Sleeve Manufacture

A combination of [

]a,b,c,e

The qualification and production bimetallic TREX's* were metallographically and NDE inspected prior to processing into tubing. The bimetallic TREX's were evaluated for bond integrity, OD and ID surface condition, and clad thickness uniformity.

Routine ultrasonic testing techniques for wall thickness verification were employed for verifying bond integrity. Two reference standards were employed to simulate discontinuities at the Inconel Alloy 625/Inconel Alloy 690 interface. [

]a,c,e All of the qualification TREX's in comparison were ultrasonically inspected and no lack of bond areas detected. In addition to the ultrasonic inspection, ID borescope and OD fluorescent evaluations were performed. No indications were observed.

*Tube Reduced Extrusion Process

Metallographic sections were taken for each bimetallic TREX, as well as each mill length of finished tubing. Clad thickness measurements on the TREX samples allowed for an evaluation of clad uniformity, while measurements on the finished tubing was used to meet drawing requirements.

Dimensional requirements of the finished sleeving such as diameter, wall thickness, clad thickness, length, and straightness have in general met the requirements as defined by the appropriate sleeve detail drawing.

Results of tensile testing indicate that the Inconel Alloy 690 inner material meets the mechanical property requirements specified in Code Case N-379, i.e., 40 ksi minimum yield strength and 30 percent minimum elongation. Tensile tests were performed with the clad removed.

6.1.2.3 Metallurgical Characterization

Metallographic evaluation of qualification and production bimetallic material has indicated [the presence of Al_2O_3 stringers. a,b,c,e

In addition to structural tests to evaluate the impact of the [ ][a,c,e,b] pitting tests were performed to verify that the pitting resistance of the Inconel Alloy 625 clad was not reduced. Electrochemical pitting potential measurements for bimetallic sleeving containing [ ][a,b,c,e] were comparable with values obtained for wrought Inconel Alloy 625. Immersion of thermal treated Inconel Alloy 625/Inconel Alloy 690 bimetallic, mill annealed Inconel Alloy 600 and wrought Inconel Alloy 625 to a [ ][a,b,c,e] further verified the resistance of the bimetallic material. Extensive pitting of the mill annealed Inconel Alloy 600 sample was observed, while no pitting was observed on the outside surface of the bimetallic or on the wrought Inconel Alloy 625.

The effect of processing parameters on the properties and microstructure of bimetallic material have been evaluated. Bimetallic tubing was given various mill anneal and thermal treatments. The thermal treatment is required to optimize the SCC resistance of the Inconel Alloy 690. Hardness measurements and the microstructure of both the Inconel Alloy 625 clad and the Inconel Alloy 690 base metal were evaluated.

][a,b,c,e] hours was selected as the reference treatment for the bimetallic tubing.

6.1.2.4 Corrosion Evaluation

The outer bimetallic sleeve material is to possess demonstrated resistance to pitting corrosion, while the total wall is to exhibit resistance to other modes of corrosion. A series of corrosion tests are being performed to verify the performance of thermally treated Inconel Alloy 625/Inconel Alloy 690

bimetallic tubing under off-chemistry secondary side and primary water environments. The objectives of these tests are: (1) to demonstrate that the outer Inconel Alloy 625 clad on the bimetallic provides similar pit initiation resistance inherent in wrought Inconel Alloy 625, and (2) to demonstrate that the thermally treated Inconel Alloy 690 inner layer provides stress corrosion resistances in both off-chemistry secondary and primary side environments.

The material and corrosion verification program for Millstone Unit 2 is an ongoing program. Results obtained to date are being reported. Additional results will be reported as they become available.

6.1.2.4.1 Beaker Tests

Specimens of pilot bimetallic Inconel Alloy 625/Inconel Alloy 690, Inconel Alloy 690, Inconel Alloy 600, and wrought Inconel Alloy 625 were exposed to various oxygenated chloride type environment. (Refer to Table 6.1-3). [ ]^{a,b,c,e} and the length of exposure was 6 weeks. Sludge composition is presented in Table 6.1-4.

[

]^{a,b,c,e}.

6.1.2.4.2 Electrochemical Testing

The relative pitting resistances of Inconel Alloy 600 (Ht 9837), Inconel Alloy 690 (Ht 9780), wrought Inconel Alloy 625 (Ht 42A5As) and bimetallic tubing were evaluated in aqueous solutions [ ]^{a,c,e} The results of pitting potential measurements are summarized in Table 6.1-6. These pitting potential values were obtained from anodic polarization curves. As would be expected, Inconel Alloy 625 (both wrought and bimetallic) exhibited significantly higher pitting potentials than either Inconel Alloy 690 or Inconel Alloy 600. These results

indicate that the Inconel Alloy 625 outer layer on the bimetallic tubing should exhibit a pitting resistance which is equal to, or better than, the well established high pitting resistance of wrought Inconel Alloy 625.

Confirmation of the pitting resistance of the bimetallic tube was obtained by exposing the Inconel Alloy 625 outer layer of the bimetallic tube and a thermally treated Inconel Alloy 690 tube in the [

]a,c,e The Inconel Alloy 690 tubing exhibited pitting, while the Inconel Alloy 625 on the bimetallic tube was unattacked.

6.1.2.4.3 Autoclave Testing

The corrosion and stress corrosion cracking resistance of bimetallic sleeving material was evaluated by a series of autoclave exposures. Both primary and off-chemistry secondary side environments were evaluated. (Refer to Table 6.1-7). Specimen configurations included C-rings stressed to 90 percent and 150 percent of yield strength, U-bends, corrosion coupons, and straight length of tubing. Pilot and qualification bimetallic Inconel Alloy 625/Inconel Alloy 690, mill annealed and thermal treated Inconel Alloy 600 and Inconel Alloy 690, and wrought Inconel Alloy 625 were included in all tests.

]a,b,c,e

These results have confirmed that the thermally treated Inconel Alloy 625/Inconel Alloy 690 bimetallic material provides improved resistance to pit initiation while providing SCC resistance. Elevated temperature tests in relevant Millstone Unit No. 2 off-chemistry secondary side environments have resulted in extensive pitting of mill annealed Inconel Alloy 600 material, while the bimetallic material exhibited zero to minimal attack. [

]b,c,e No cracking of Inconel Alloy 625 has been observed in primary water.

6.1.2.4.4 Heat Transfer Testing

These tests are being performed to evaluate the bimetallic sleeve configuration integrity under thermal and chemical conditions which are comparable to or more aggressive than those expected to be found in the regions of the steam generators in which pitting has occurred. These tests assume a low level, secondary side contamination and through-wall penetrations of the existing tube. Under these conditions, the behavior of the annulus between the tube and sleeve is evaluated.

Two single tube model boiler, one heated crevice and one modular model boiler tests are being performed using bimetallic Inconel Alloy 615/Inconel Alloy 690 sleeving material produced from the pilot program. Schematic of the test configuration for the single tube and heated crevice tests is presented in Figure 6.1.1. The heated crevice test, and one of the two single tube model boiler tests were terminated after 12 weeks of exposure to a [ ]^{a,c,e} environment. Minimal pitting was observed on the mill annealed Inconel Alloy 600 outer tube, while [ ]^{b,c,e} Evidence of sludge deposit within the annulus has been observed.

Heat transfer testing is continuing in an attempt to produce the environmental conditions which will result in pitting of the mill anneal Inconel Alloy 600 outer tube and thereby directly evaluate the performance of the bimetallic sleeve.

6.1.3 MECHANICAL TESTING

The primary functions of the sleeve repair are to span a degraded region in the steam generator tubing and to maintain the steam generator tubing primary-to-secondary pressure boundary under normal and accident conditions. A rigorous testing program was conducted to verify the sleeve design for the Millstone 2 steam generators. The objectives of the mechanical testing program included:

- Verify the structural strength of the sleeved tube under normal and accident conditions.

- Verify the fatigue strength of the sleeved tube under transient loads representing 35 years of operation.

- Confirm capability for performance of tubes sleeved in off-nominal conditions such as tube support plate denting

- Establish the process parameters required to achieve sleeve/tube capability.

The acceptance criteria used to evaluate the sleeve performance were leak rates based on Northeast Utilities specifications. Over 100 test specimens were used to verify the design and to establish process parameters. Testing encompassed static pressures, and static and cyclic temperatures and loads.

6.1.3.1 Leak Test Acceptance Criteria

The leak rate criteria that were established based on Technical Specifications and regulatory requirements(1) are shown in Tables 6.1-11 and 6.1-12. Leak rate measurement is based on counting the drops occurring in a 10-20 minute period. Conversion to volumetric measurement is based on a factor of 19.8 drops per milliliter.

6.1.3.2 Basic Test Plan and Conditions

The test program consisted of subjecting specimens representing the lower joint, the upper HEJ, and the two joints together (i.e., fixed-fixed mock-up) to normal operating and postulated accident conditions and measuring the leak rate for all of these conditions. The various tests that were imposed on each joint are described in the subsequent paragraphs. The exact sequence of testing through which each joint was passed is described in the section for that joint.

1. Leak Resistance Test

The sleeve was pressurized under the following conditions and the leak rate was measured at that condition:

a. 600°F and a primary-to-secondary pressure differential of 1600 psi to simulate normal operating conditions

b. 600°F and primary-to-secondary pressure differential of 2485 psi to simulate a steamline break accident condition

c. Room temperature and a primary-to-secondary pressure differential of 1485 psi and 2485 psi to compare to the first two conditions and thereby determine the effect of temperature on the leak rate

d. Room temperature and a primary-to-secondary pressure differential of 3110 psi to simulate a hydrostatic pressure test that could be performed on the steam generators

e. 600°F and a primary-to-secondary pressure differential of 3110 psi as a limiting case.

f. 530°F and a secondary-to-primary pressure differential of 1035 psi for 24 hours to simulate a loss-of-coolant accident.

g. 640°F and a primary-to-secondary pressure differential of 2285 psi while subjected to compressive loading to simulate a steam line break accident.

Note: The conditions set up in the primary-to-secondary leak test resulted in the application of tensile loads at the joints. It was initially thought in earlier programs that an abnormal loading was being applied which would bias the leak rate. Therefore, in the first stages of an earlier program the tensile load was counteracted by applying the equal compressive load at the specimen end plugs. However, it was determined by test that the equalizing end plug loading had a negligible effect on leak rate and the leak resistance testing for Millstone 2 was performed without end plug load counteraction.

2. Thermal Cycling Test

The temperature of the joint was cycled from below 120°F to 600°F and returned to below 120°F to simulate the plant heatup/cooldown cycle. The total number of heatup/cooldown cycles (100) to which joint specimens were submitted was determined by multiplying the design stress cycles of the steam generator by a factor of approximately 2.8.

3. Fatigue Test

The joint was heated to 600°F and pressurized to 1600 psi to simulate normal operating conditions. The external axial load was cycled from approximately 0 to 2200 lbs compression. This caused the sleeve load to cycle from [

]^{a,c,e} This simulated the most stringent loadings imposed on the joint due to the plant loading/unloading transient. The largest tensile load is associated with degraded steam generator tubes not dented at the first support grid while the largest compressive load is associated with steam generator tubes dented at the first support grid.

6.1.3.3 Test Program for the Lower Joint

6.1.3.3.1 Description of Lower Joint Test Specimens

In this arrangement (See Figure 6.1-2), a hollow cylindrical carbon steel collar was used to simulate a unit cell of the tubesheet. A short length of Alloy 600 tubing was expanded against and welded to the collar. The tube expansion was accomplished by light rolling to simulate the full depth explosive expansion that was used in Millstone Unit 2. The collar was not clad on the end with Alloy 600, as are the Millstone Unit 2 steam generator tube sheets. Previous testing with this type test specimen has indicated that the Alloy 600 clad is not critical to the successful fabrication of the joint. A short length of sleeve was then inserted into the tube/collar, hydraulically expanded, and then hard rolled to make a lower joint specimen.

In addition to the lower joint specimen described above, a limited number of test specimens were made using collar and tube assemblies produced by the manufacturer of the steam generator. In these assemblies, the tubes were roll expanded against the collar, explosively expanded against the collar inside diameter and were then welded to the collar. Also, the collar bottom surface was clad with Alloy 600.

These collar and tube assemblies, therefore, simulated the steam generator tubesheet closely. Sleeves were installed in these collar-tube assemblies using the same techniques as used for the earlier specimens.

6.1.3.3.2 Description of Verification Tests for the Lower Joint

The as-rolled specimens were fabricated and tested in the sequence described below. (Refer to Section 6.1.3.2 for descriptions of each test.)

1. Initial leak resistance test: The leak rate was determined at room temperature and at 600°F for pressures of 1485 (RT), 1600 (600°F), 2485, and 3110 psi. These tests established the leak resistance of the lower joint after it has been installed in the steam generator and prior to long-term operation.

2. Some of the specimens were thermally cycled for 100 cycles.

3. Some of the specimens were fatigue loaded for 30,000 cycles.

4. Some of the specimens were subjected to push-out tests and some to pullout tests, both at room temperature and 600°F.

5. Specimens were leak tested as in Step 1 following the thermal cycling and fatigue testing.

6. Some of the specimens were subjected to steam line break accident simulations.

6.1.3.3.3 Results of Verification Tests for Lower Joint

The results of the verification test program are given in Table 6.1-13 (5 sheets). The results of all tests are given along with the parameters that were used to make the test specimens.

6.1.3.4 Test Program for the Upper HEJ

6.1.3.4.1 Description of the Upper HEJ Test Specimens

The upper joint (see Figure 6.1-3) consists of a piece of sleeve material fastened into a piece of Inconel 600 tube. The sleeve is first hydraulically expanded against the tube over a short length. It is then hard rolled against the tube over a length within the hydraulically expanded length. This joint is called a hybrid expansion joint (HEJ) because of the combination of hydraulic and mechanical expansion.

6.1.3.4.2 Description of Verification Tests for the Upper HEJ

The verification test program for the upper HEJ was similar to that for the lower joint. The description of each test is given in Section 6.1.3.2.

The upper HEJ test specimens were subjected to leak resistance tests, thermal cycling, push-out and pull-out tests, and fatigue tests. The leak rate was determined before and after many of these tests. Some of the specimens were also subjected to steam line break accident simulations and to loss-of-coolant accident loadings.

6.1.3.4.3 Results of Verification Tests for the Upper HEJ

The results of the verification test for the Upper HEJ are given in Table 6.1-14 (5 pages). This table lists the results of all the tests along with the parameters that were used to make the test specimens.

6.1.3.5 Test Program for the Fixed-Fixed Mock-Up

6.1.3.5.1 Description of the Fixed-Fixed Mock-Up

The fixed-fixed mock-up is a partial simulation of the steam generator that allows the formation and testing of both sleeve joints (lower and upper HEJ) in one tube sample. The mock-up consists of three carbon steel plates spaced apart to simulate the tube sheet and first support plate (grid). Sections of steam generator tubing are installed through these plates. They are fastened to the bottom plate and support grid by hard rolling. In this way they simulate tubes that are dented and/or joined to the support grid by accumulated sludge. This provides axial and rotational fixity to the tube at both ends.

Full length sleeves, seven at a time, were installed in this mock-up using the processes developed for the individual lower and upper HEJ specimens except that the tooling was more prototypic of that to be used in the steam generators.

6.1.3.5.2 Description of Test for the Fixed-Fixed Mock-Up

The fixed-fixed mock-up, with sleeves installed, was subjected to leak resistance testing. For this test, the tubes were plugged at their top ends and water under pressure was introduced through their bottom ends. A small hole was placed through the tube wall, between the lower joint and upper HEJ, so that any substantial leakage past either joint could be detected.

6.1.3.5.3 Results of Test for the Fixed-Fixed Mock-Up

The results of the tests with the Fixed-Fixed Mock-Up are given in Table 6.1-15. This table shows the results of the room temperature leak tests on the seven tubes with sleeves installed along with parameters that were used to make the test specimens.

6.1.3.6 Effects of Sleeving on Tube-to-Tubesheet Weld

The effect of hard rolling the sleeve over the tube-to-tubesheet weld had been examined in testing for the San Onofre sleeving program. The San Onofre testing is comparable to the Millstone 2 testing. The torque used at San Onofre is comparable to that to be used at Millstone 2 and the radial forces transmitted to the weld should be comparable. Tests of the San Onofre configuration showed no tearing or other degrading effects on the weld after hard rolling. Further, no degrading effects on the Millstone 2 test specimen welds have been observed. Therefore, no significant effect on the tube-to-tubesheet weld is expected for the Millstone 2 configuration.

6.1.3.7 Establishment of Sleeve Joint Main Fabrication Parameters

6.1.3.7.1 Lower Joint

The selected values for significant lower joint fabrication parameters are listed in Section 4.0. The main parameter for fabrication of acceptable lower joints is sleeve wall thinning. Sleeve wall thinning is determined by the hard roller stalling torque. Accordingly, the rolling torque was varied to achieve the desired [ ]^{a,c,e} total sleeve wall reduction (refer to Figure 6.1-4.) The lowest torque at which the desired thinning was achieved was [ ]^{a,c,e} Torques used between [ ]^{a,c,e} were for the verification testing as discussed in the Lower Joint Mechanical Testing portion in Section 6.1.3.

6.1.3.7.2 Upper HEJ

The selected values for the significant upper HEJ fabrication parameters are given in Section 4.0. The main parameter for fabrication of upper HEJ's which meet the leak rate acceptance criteria is tube outside diameter increase due to roll expansion. This effect is shown typically in Figure 6.1-5 for Westinghouse Model 44 steam generators (Point Beach and Indian Point 3) and for Millstone Unit 2 as an upper bound. [ ]^{a,c,e}

In the San Onofre sleeving project, a parameter of lesser importance to HEJ leak rate performance was found to be hydraulic expansion axial length. Longer hydraulic expansion axial lengths resulted in HEJ's of slightly lower leak rates. Therefore, the Millstone 2 hydraulic expansion axial length [

]a,b,c,e

6.1.3.8 Discussion of Results

6.1.3.8.1 Lower Joint

From the test results obtained (see Table 6.1-13) the following conclusions are reached:

a. Initial leak rates, both at room temperature and at 600°F, were all well below 22.5 drops per minute (normal operating pressure leak rate criteria - see Table 6.1-11) when tested at pressure up to 3110 psi. The joint test specimens were formed with roll torques ranging from [ ]a,c,e which encompasses the roll torques expected to be used during actual sleeve installation.

b. Thermal cycling between <120°F and 600°F had no detectable adverse influence on joint leak rate. The leak rate after testing remained at essentially zero drops/minutes.

c. Fatigue testing of lower joints had no discernable adverse effect on joint leak resistance or structural capabilities. Leak rates remained at essentially zero drops/minute.

d. For push-out and pull-out tests, all joints tested exhibited loads for initial slip, where observable, or loads for start of non-linear load-deflection, above the effective axial loads that were applied during the fatigue tests (see Section 6.1.3.2.3).

6.1.3.8.2 Upper HEJ

From the results obtained (see Table 6.1-14), the following conclusions are reached:

a. Initial leak rates at room temperature and 600°F at pressures between 1485 and 3110 psi were well below 22.5 drops/minute (most had zero drops/minute).

b. Thermal cycling between < 120°F and 600°F had no detectable adverse influence on joint leak rate. One joint exhibited a leak rate above 0.8 drops per minute. This occurred at room temperature at 1485 psi after 30 cycles. After 100 cycles this test rate returned to zero.

c. Fatigue tests of upper HEJ had no discernable adverse effect on joint leak resistance or structural capabilities. Leak rates remained at zero drops/minute under all conditions tested.

d. For push-out and pull-out tests, all joints tested (except one) exhibited loads for initial slip, where observable, or loads for start of non-linear load-deflection, above the effective axial loads that were applied during the fatigue tests (see Section 6.1.3.2.3). One joint had an initial slip under push loading that was 37 lbs below the applicable fatigue loads. Otherwise, this joint behaved similarly to the others and was acceptable.

e. The leak rates observed during a simulated steam line break test were well below the acceptance criteria.

f. The leak rates observed during a simulated LOCA remained at essentially zero drops per minute during the entire test, which is well below the acceptance limit.

6.1.3.8.3 Fixed-Fixed Mock-Up

The results of the leak tests on the fixed-fixed mock-up (see Table 6.1-15) were essentially the same as the leak tests on the individual lower and upper joint test specimens. No leakage was observed at room temperature under pressures up to 3110 psi. In addition, the lower joint wall thinning and the upper HEJ total tube leakage were within the ranges experienced by the individual joint specimens. These results both confirm the results of the individual joint tests and indicate that there is no apparent structural interaction between the lower and upper joints.

6.1.3.9 Summary

Results of the verification test using alloy 625/690 bimetallic sleeve material showed that joints can be made that exhibit leak rates that are acceptably low and are as low or lower than leak rates observed with single thickness (alloy 600 and alloy 690) sleeve material. These joints, with alloy 625/690 bimetallic sleeves, also exhibit completely acceptable structural strength, as determined by push, pull, and fatigue tests. Finally, joint leakages when subjected to simulated accident conditions (SLB and LOCA) are well below acceptance limits.

The sleeving process to be used at Millstone Unit 2 has been reviewed for its impact on the safety of the steam generators. The bimetallic sleeves are hydrostatically tested after fabrication at 125 percent of Reactor Coolant System design pressure. The sleeve assembly has been analyzed in accordance with applicable criteria of Section III of the ASME Code. The sleeve is inserted into the tube and expanded at each end by the formation of a hybird expansion joint (HEJ), which is a combination of a hydraulic expansion and a mechanical hard roll. Pilot lot hydrostatic testing at pressures simulating normal operation and faulted conditions have shown acceptable leak-limiting characteristics of the sleeve assembly. The sleeve material has been shown to exhibit excellent resistance to pitting attack, such as experienced at Millstone 2, while maintaining resistance to general and primary water corrosion. The ASME has approved this bimetallic material as Code Case N-379. The sleeve assembly is capable of inservice inspection as required by

ASME Code Section XI and the guidelines of Regulatory Guide 1.83. Laboratory development work has shown that the sleeve assembly can adequately be inspected by present eddy current techniques. Analytical and experimental verification has also been performed to show that the sleeve assembly can withstand the loads imposed by design, operating, and test conditions. The results of the testing and analyses described in Chapter 6 of this Report demonstrate that the sleeve assembly is an acceptable means of maintaining degraded tubes in service. The implementation of the sleeving process does not pose a hazard to the safe operation of the Millstone Unit 2 steam generators.

6.1.3.10 References - Section 6.1

1. NUREG-0651, "Evaluation of Steam Generator Tube Rupture Events."

TABLE 6.1-1

COMPOSITION OF CANDIDATE OUTER SLEEVE
MATERIALS EVALUATED FOR BIMETALLIC USAGE

Composition, Wt Percent

Alloy	Fe	Cr	Ni	C	Mo	W	Ti	Others
Sea-Cure	Bal	27	1.25	0.02	3.5	-	0.50	-
Inconel 625	5	20/23	Bal	0.10	8/10	-	0.40	3.15/4.15 Nb + Ta
Incoloy 825	Bal	19.5/23.5	38/46	0.05	2.5/3.5	-	0.6/1.2	1.5/3.0 Cu
Hastelloy C-276	4/7	14.5/15.5	Bal	0.02	15/17	3/4.5	-	2.5 Co 1 Mn
AL6X	-	20	24	-	6	-	-	-
Inco 671	-	48	52	-	-	-	-	-

TABLE 6.1-2

PITTING EVALUATION TEST ENVIRONMENTS

Test environments judged most aggressive in causing pitting attack:

[ ]a,c,e

*Sludge Composition: [ ]a,c,e

TABLE 6.1-3

ENVIRONMENTS USED FOR BEAKER EXPOSURES

a,c,e

TABLE 6.1-4

SLUDGE COMPOSITION FOR BEAKER TESTS

Species	Percent (by weight)

b,c,e

Sludge Analysis based on sludge sample removed from Millstone Unit No. 2 during the 1981-1982 refueling outage.

TABLE 6.1-5

MILLSTONE SLEEVE MATERIALS: PITTING TESTS 125°F

6-WEEK EXPOSURES, EXPANDED AND STRAIGHT-LENGTHS

Test 1 [ ] a,c,e		Test 2 [ ] a,c,e		Test 3 [ ] a,c,e	
A	B	A	B	A	B

[ ] a,c,e

TABLE 6.1-6

PITTING POTENTIALS IN DEAERATED
[ ]a,c,e

---------------Pitting Potentials (mv / SEC----------------

[ ] a,c,e

TABLE 6.1-7

ENVIRONMENTS AND TEMPERATURES FOR AUTOCLAVE TESTING

Environment	Chemistry

a,c,e

TABLE 6.1-8

AUTOCLAVE IMMERSION
RESULTS AFTER 2800 HRS

[ ]a,c,e

Material	Pit Depth (Mils)		Pit Depth (Mils)		Pit Depth (Mils)	
	Envir. No. 2 No Sludge	Envir. No. 3 Sludge	Envir. No. 4 No Sludge	Envir. No. 5 Sludge	Envir. No. 6 No Sludge	Envir. No. 7 Sludge

[ ]a,c,e

[ ]a,c,e

TABLE 6.1-9

TEST PROGRAM ISSUES

1. Mechanical Test Program

   - Leak Resistance of Lower Joint and Upper Hybrid Expansion Joints (HEJ) under normal operating conditions.

   - Effect of thermal and mechanical cyclic loads on the leak resistance and structural capabilities of Lower Joints and Upper HEJs.

   - Structural strength of Lower Joints and Upper HEJs under actions of push and pull loads.

   - Response of Lower Joints and Upper HEJs to simulated steamline break accidents.

   - Response of Upper HEJs to simulated Loss of Coolant Accidents (LOCA).

TABLE 6.1-10 (Page 1 of 2)

DESIGN VERIFICATION TEST PROGRAM - MECHANICAL

Issue	Description of Test(1)	San Onofre (SCE)	Point Beach and Indian Point 3 Application	Millstone Unit 2
1. Leak-Limiting capabilities of HEJ.	Millstone Unit 2 Reference Configuration Initial Leak Test (Primary to Secondary at 1485 psi at R.T. and 1600 at 600°F)	Met leak criteria (total S/G leakage < 18 gpm at 2400 psi and 600°F).	Met leak criteria.	Met leak rate acceptance criteria.
2. Structural capabilities of HEJ after axial cyclic loading.	Millstone Unit 2 Reference configuration: 30,000 cycles 100 to 2200 pound compression at 1600 psi Δp and 600°F.	Met structural criteria.	Met structural criteria.	No structural failure.
3. Structural capabilities of HEJ after axial and radial cyclic loading.	Simulate loading and unloading, and heatup and cooldown transients (Equivalent Test)	Not performed.	Analysis portion of equivalent test showed that axial cycle loading test produced substantially more fatique damage than would have been produced in this test. Test not performed.	Test not performed. Axial cyclic loading (see No. 4) more severe.
4. Leak-limiting capabilities of HEJ after axial cyclic loading.	Millstone Unit 2 Reference configuration: Leak test at 1485, 2485, and 3110 psi at R.T. and 1600, 2485, and 3110 psi at 600°F after axial loading cycles.	Met leak criteria.	Met leak criteria.	Met leak rate acceptance criteria.
5. Structural capabilities of HEJ during FLB accident conditions.	Reference configuration: Measure axial yield load.	Met criteria of being greater than 1636 lb.	Met structural criteria.	Not performed. (See Steam Line Break test, No. 10.)
6. Leak-limiting capabilities of HEJ during accident conditions.	Millstone Unit 2 Reference configuration: Leak Test at 2485 and 3110 psi at R.T. and 600°F.	Met criteria.	Met leak criteria.	Leak rate below 0.5 drops/minute.

TABLE 6.1-10 (Page 2 of 2)

DESIGN VERIFICATION TEST PROGRAM - MECHANICAL

Issue	Description of Test[1]	San Onofre (SCE)	Point Beach and Indian Point 3 Application	Millstone Unit 2
7. Leak limiting capabilities of HEJ with secondary side pressure greater than primary side pressure.	Millstone Unit 2 Reference configuration: leak test at R.T. and 530°F and differential pressures up to 1035 psi.	Met criteria.	Met criteria. (LOCA condition - elevated temp-also tested)	Met LOCA leak rate acceptance criteria.
8. Leak-tight capabilities of lower joint after cyclic loading.	Thermal cycles from <120°F to 600°F, 100 leak test at R.T. and 600°F at 1485, 2485, and 3110 psi at R.T. and 1600, 2485, and 3110 psi at 600°F.	Met criteria.	Met leak criteria.	Met leak rate acceptance criteria.
9. Structural capabilities of lower joint after cyclic loading.	Thermal cycles from R.T. to 650°F, 8500 axial loading cycles of ± 2000 lb.	Met structural criteria.	Met structural criteria.	Test not performed (see push-out and pull-out test, No. 12)
10. Structural and leak limiting capabilities of HEJ during SLB accident conditions.	Millstone Unit 2 Reference configuration: Leak Test at R.T. and 640°F at 2285 psi and with load applied to 5500 lb or joint displacement of 0.05 in., whichever comes first.	Not tested.	Not tested.	Met leak rate acceptance criteria.
11. Leak limiting capabilities of lower joint.	Millstone Unit 2 Reference configuration: Leak test at 1485, 2485, 3110 psi at R.T. and 1600, 2485, and 3110 psi at 600°F.	Met criteria.	Met criteria.	Met leak rate acceptance criteria.
12. Structural capabilities of upper HEJ and lower joints in response to push and pull test.	Axial load joints in tension or compression at R.T. or 600°F.	Test not performed. Included as part of Nos. 2 and 9.	Test not performed, included as part of Nos. 2 and 9.	Met acceptance criteria.

(1) Test values specific for Millstone Unit 2; values for San Onofre, Point Beach, and Indian Point 3 are approximately equivalent.

TABLE 6.1-11

ALLOWABLE LEAK RATES FOR
MILLSTONE 2 STEAM GENERATORS
(Normal Operation)

Condition	Allowable Leak Rate++	Allowable Leak Rate per Sleeve
Normal Operation	0.5 gpm per steam generator	0.0002 gpm* 1.14 ml/min or 22.6 drops/min

* Based on 1500 sleeves per steam generator.

++ Technical Specification Limit.

TABLE 6.1-12

Accident Condition Leak Rates for Millstone 2 Steam Generators

NOTE: These values are included to use as a comparison basis for the leak rates resulting from the accident conditions simulated in the verification testing. Test results from the verification test program indicate significant safety margin to the amounts of leakage listed below.

	Limiting Leak Rate	Leak Rate per Sleeve***	
Postulated Accident Condition (Steamline Break)	[	]	a,c,e
Postulated Accident Condition (LOCA - Secondary Side Pressure greater than Primary Side Pressure)	1300 gpm**	0.43 gpm (1634 ml/min or 32343 drops/min)	

* [ ] a,c,e

Steamline break accident is assumed so that highest Δp, and therefore highest primary-to-secondary leakage occurs. Analysis also assumes Tech. Spec. coolant activity of 1.0μ Ci/g I-131 dose equivalent prior to the transient, an accident-initiated iodine spike, no partitioning in the faulted steam generator, and the SLB occurring outside containment. This analysis was done in accordance with Standard Review Plan 15.1.5, Appendix A, Revision 2.

** Based on NUREG-0651 "Evaluation of Steam Generator Tube Rupture Events," which defines 1300 gpm as limit for secondary-to-primary leakage that will not affect core cooling due to steam binding (i.e., peak clad temperature less than 2200°F).

*** Based on 3000 sleeves.

TABLE 6.1-13 *5 PAGES*

VERIFICATION PHASE TEST RESULTS - LOWER JOINT

ALLOY 625/690 BIMETALLIC SLEEVE

b,c,e

Specimen No.
VBL-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20

TABLE 6.1-14 5 PAGES

VERIFICATION PHASE TEST RESULTS - UPPER JOINT

ALLOY 625/690 BIMETALLIC SLEEVE

b,c,e

Specimen No.
VBU-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20

TABLE 6.1-15

VERIFICATION PHASE TEST RESULTS - FIXED-FIXED MOCK-UP

ALLOY 625/690 BIMETALLIC SLEEVE

b,c,e

(1) Center tube - unable to measure tube post-roll OD.

[ ]

FIGURE 6.1-1: SCHEMATIC OF HEATED CREVICE AND SINGLE MODEL BOILER TEST CONFIGURATION

FIGURE 6.1-2 LOWER JOINT AS-ROLLED TEST SPECIMEN

FIGURE 6.1-3: HYBRID EXPANSION JOINT TEST SPECIMEN
(The Leak Path, If Any Leakage Exists, Is Shown By The Dotted Line)

Figure 6.1-4 Roll Torque vs. Wall Reduction for Sleeves Roll Expanded into Tube/Tubesheet Specimens

Figure 6.1-5 Leak Rate vs. Tube O.D. Mechanical Roll Expansion for Upper HEJ

6.2 ANALYTICAL VERIFICATION

6.2.1 INTRODUCTION

This section contains the structural evaluation of the Millstone 2 sleeve and tube assembly in relation to the requirements of the ASME Boiler and Pressure Vessel Code, Section III, 1980 edition for the cladded sleeve. For the existing tubes and tubesheet, the 1968 edition through the Summer 1969 Addenda is applicable. In general, the analytical procedure for the stress evaluation is the same as previously done for the sleeving effort at San Onofre, Point Beach, and Indian Point. Using the WECAN[1] program, stress components are taken directly from the analysis of finite element models of the tube-sleeve assembly. Separate scaled-up unit pressure runs and thermal transient runs are first made and then properly combined by the WECEVAL[4] program. The assembly configuration is shown in Figure 6.2-1. Figures 6.2-2 and 6.2-3 represent the upper joint and the lower joint geometries, respectively, which were used in the analysis. The actual joint geometries, as shown in Figures 6.2-15 and 6.2-16, were also considered.

6.2.1.1 Critical Sections to Be Evaluated

The sections considered in the evaluation of the tube-sleeve assembly are generally at the changes in diameters, shown also in Figures 6.2-2 and 6.2-3. Additional sections with constant diameters are included in this evaluation.

<u>Section A-A</u>

This section is located [ ]^{a,c,e} and represents the uppermost boundary of the hydraulically expanded zone.

<u>Section B-B</u>

This section is [ ]^{a,c,e} and represents the uppermost boundary of the rolled portion of the upper joint.

Section C-C

This section is [ ]^{a,c,e} and represents the lowermost boundary of the rolled portion of the upper joint.

Section D-D

This section is [ ]^{a,c,e} and represents the lowermost boundary of the hydraulically expanded zone.

Section E-E

The section represents the tube-sleeve assembly as normally assembled.

Section F-F

This section is located [ ]^{a,c,e} and represents the topmost part of the expanded portion of the tube in the tubesheet.

Section G-G

This section is located [ ]^{a,c,e} and represents the expanded sleeve as assembled in the tubesheet.

Section H-H

This section is located [ ]^{a,c,e} and represents the topmost boundary of hydraulic expansion done on the sleeve inside the tubesheet.

Section I-I

This section is located [
]^{a,c,e} and represents the topmost boundary of the rolled zone of the sleeve in the tubesheet.

It is to be noted that all the radial dimensions are shown on the two figures. The additional sections which were also included in the evaluation were cut at locations of constant diameters and are as follows:

Section Z-Z

This section is for the tube only and is located just above the above top of the sleeve in the upper joint.

Section Y-Y

This section is for the hydraulically expanded tube and sleeve and is located between Sections C-C and D-D.

Section X-X

This section is similar to Section E-E but only located just above the tube-sheet.

Section W-W

This section is for the rolled tube/sleeve assembly in the tubesheet and is located below Section I-I.

6.2.2 COMPONENT DESCRIPTION

For the sleeve/tube assembly, the main portions are two joints, an upper joint and a lower joint, and straight sections of the sleeve and tube between the

two joints. For Millstone, a [ ]^{a,c,e} sleeve was analyzed. Two finite element models were developed to represent the HEJ* (upper joint) and the lower joint areas. The load conditions imposed on the model were consistent with those for the [ ]^{a,c,e} sleeve on the hot leg side. In developing the roll region of the model, the estimated bulging at the O.D. of the sleeve and tube were evaluated in combination with the nominal tube and sleeve wall thickness. However, the slight wall thinning was neglected for the stress levels computed in the roll transition regions.

The tube material is Inconel 600; the sleeve material is Inconel 690 with Inconel 625 cladding on the OD. The tubesheet is low alloy carbon steel, SA508 Class 2 with Inconel cladding on the primary face.

6.2.3 MATERIAL PROPERTIES

6.2.3.1 Tube

The following material properties were used for the tube in this analysis.** Temperature dependence was represented through temperature T (°F) where applicable.

1. Material Strength Properties - See Table 6.2-1.

2. Modulus of Elasticity - as incorporated in the finite element analysis, E (psi):

$$E(T) = 3.2743E{+}07 - 2.0938E{+}04(T) + 1.0631E{+}02(T)^2 - 3.1638E{-}01(T)^3 + 4.3873E{-}04(T)^4 - 2.2847E{-}07(T)^5$$

* Hybrid Expansion Joint

** All properties are as specified in ASME Boiler and Pressure Vessel Code - Section III, Appendix I.

3. Mean Coefficient of Thermal Expansion, α (in /in -°F):

$$ALP(T) = 6.6490E-06 + 3.0965E-09(T) - 1.8648E-12(T)^2$$

4. Poisson's ratio, ν (dimensionless):

$$NU(T) = 0.3$$

5. Density, ρ (lb -sec ^{2}/in ^{4}):

$$DENS(T) = 7.9593E-04 - 1.7811E-08(T) - 1.4905E-12(T)^2$$

6. Thermal Conductivity, κ (Btu/sec-in -°F):

$$K(T) = 1.9563E-04 + 3.2720E-08(T) + 2.8754E-10(T)^2 - 4.3061E-13(T)^3 + 2.3562E-16(T)^4$$

7. Specific Heat, Cp (Btu-in /lb-sec^2-°F):

$$CP(T) = 3.9688E+01 + 2.1540E-02(T) - 2.5559E-05(T)^2 + 1.8083E-08(T)^3$$

6.2.3.2 Sleeve

The sleeve material properties are as follows:

1. Material Strength Properties - See Table 6.2-2.

2. Modulus of Elasticity, E (psi):

$$E(T) = 2.9981E+07 - 3.7447E+03(T) - 4.2191E+00(T)^2 + 4.5576E-03(T)^3$$

3. Mean Coefficient of Thermal Expansion, α (in/in-°F):

ALP (T)= 6.800E-06 + 1.7500E-09(T) - 1.2500E-12 $(T)^2$

4. Poisson's ratio, ν (dimensionless):

NU(T) = 0.3

5. Density, ρ ($lb\text{-}sec^2/in^4$):
(Assumed the same as I600)

DENS(T) = 7.9593E-04 - 1.7811E-08(T) - 1.4905E-12$(T)^2$

6. Thermal Conductivity, κ (Btu/sec-in-°F):

K(T) = 1.230E-04 + 6.4962.E-08(T) + 1.1895E-09$(T)^2$
- 8.2920E-12$(T)^3$ + 2.0667E-14$(T)^4$ - 1.6571E-17$(T)^5$

7. Specific Heat, Cp ($Btu\text{-}in/lb\text{-}sec^2\text{-}°F$):
(Assumed the same as I600)

CP(T) = 3.9688E+01 + 2.1540E-02(T) - 2.5559E-05$(T)^2$
+ 1.8083E-08$(T)^3$

6.2.3.3 Sleeve Cladding

1. Material Strength Properties

None is required for use in Design, Faulted, and Test Conditions (primary stress) per ASME Code NB-3122.1. For secondary and peak stress evaluation per ASME Code NB-3122.3, see stress allowables for clad material given in Table 6.2-3.

2. Modulus of Elasticity, E (psi):

For primary stresses: $E(T) = 0.0$
For fatigue evaluation: $E(T) = 3.2743E{+}07 - 2.0938E{+}04(T) + 1.0631E{+}02(T)^2 - 3.1638E{-}01(T)^3 + 4.38736E{-}04(T)^4 - 2.2847E{-}07(T)^5$

3. Mean Coefficient of Thermal Expansion, α (in/in-°F):

$ALP(T) = 6.6490E{-}06 + 3.0965E{-}09(T) - 1.8648E{-}12(T)^2$

4. Poisson's ratio, ν (dimensionless):

$NU(T) = 0.3$

5. Density, ρ ($lb\text{-}sec^2/in^4$):

$DENS(T) = 7.9593E{-}04 - 1.7811E{-}08(T) - 1.4905E{-}12(T)^2$

6. Thermal Conductivity, κ (Btu/sec-in-°F)

$K(T) = 1.7793E{-}04 + 9.0618E{-}08(T) + 1.6081E{-}10(T)^2 - 1.8609E{-}13(T)^3$

7. Specific Heat, Cp ($Btu\text{-}in/lb\text{-}sec^2\text{-}°F$):

$CP(T) = 3.7060E{+}01 + 1.0921E{-}02(T) - 4.3832E{-}07(T)^2 - 3.3951E{-}11(T)^4$

6.2.3.4 Tubesheet

The tubesheet material is low alloy steel of ASME classification SA 508, Class 2. The following material properties are used for the tubesheet in this analysis.

1. Material strength Properties - See Table 6.2-4.

2. Modulus of Elasticity, E (psi):

$$E(T) = 2.9819E{+}07 + 3.9199E{+}03(T) - 4.7234E{+}01(T)^2 + 1.2588E{-}01(T)^3 - 1.5900E{-}04(T)^4 + 7.2495E{-}08(T)^5$$

3. Mean Coefficient of Thermal Expansion, α (in/in-°F):

$$ALP(T) = 6.5411E{-}06 - 2.3707E{-}09(T) + 2.5664E{-}11(T)^2 - 6.8730E{-}14(T)^3 + 8.4953E{-}17(T)^4 - 3.9796E{-}20(T)^5$$

4. Poisson's Ratio, ν (dimensionless):

$$NU(T) = 0.3$$

5. Density, ρ (lb-sec^2/in^4):

$$DENS(T) = 7.3339E{-}04 - 1.3765E{-}08(T) - 3.6257E{-}12(T)^2$$

6. Thermal Conductivity, κ (Btu/sec-in-°F):

$$K(T) = 5.3402E{-}04 + 2.0660E{-}07(T) - 5.6305E{-}10(T)^2 + 2.9440E{-}13(T)^3$$

7. Specific Heat, Cp (Btu-in/lb-sec^2-°F):

$$CP(T) = 3.8830E{+}01 + 3.3211E{-}02(T) - 1.6147E{-}05(T)^2 - 6.9101E{-}08(T)^3 + 1.9092E{-}10(T)^4 - 1.2641E{-}13(T)^5$$

6.2.3.5 Air

The following material properties are used for all elements in the gap between the sleeve and the tube, as bounded by the upper and lower joints.

1. Material strength properties - None - No strength is attributed to elements in the gap.

2. Modulus of Elasticity, E (psi):

   $E(T) = 0$

3. Mean Coefficient of Thermal Expansion, α (in/in-°F):

   ALP(T) = 0.0

4. Poisson's Ratio, ν (dimensionless):

   NU(T) = 0.0

5. Density, ρ (lb-sec^2/in^4):

   DENS(T) = 1.1232 E-07

6. Thermal Conductivity, κ (Btu/sec-in-°F):

   K(T) = 3.0787E-07 + 4.2067E-10(T)

7. Specific Heat, Cp (Btu-in/lb-sec^2-°F):

   CP(T) = 91.4609 +.0097(T)

6.2.3.6 Water

The following material properties are used for all elements in the gap between the sleeve and the tube, as bounded by the upper and lower joints - when the tube is assumed to be discontinuous.

1. Material strength properties - None

2. Modules of Elasticity, E (psi):

$E(T) = 0.0$

3. Mean Coefficient of Thermal Expansion, α (in/in-°F):

$ALP\ (T) = 0.0$

4. Poisson's Ratio, ν (dimensionless):

$NU\ (T) = 0.0$

5. Density, ρ (lb-sec^2/ in^4):

$$DENS(T) = 9.4452E\text{-}05 - 1.2858E\text{-}08\ (T) - 3.8273E\text{-}11\ (T)^2 + 4.3689E\text{-}14\ (T)^4$$

6. Thermal Conductivity, κ (Btu/sec-in-°F):

$$K(T) = 7.3893E\text{-}06 + 1.3707E\text{-}08(T) - 2.6493E\text{-}11(T)^2 + 3.2671E\text{-}15(T)^3$$

7. Specific Heat, Cp (Btu-in/lb-sec^2-°F):

$$CP(T) = 3.9715E + 02 + 4.4732E\text{-}02\ (T) - 9.1182E\text{-}04\ (T)^2 + 2.2849E\text{-}06\ (T)^3$$

6.2.4 CODE CRITERIA

The ASME Code stress criteria which must be satisfied are:

1. Primary General Membrane Stress Intensity: P_m

   (a) Design Conditions: $P_m \leq S_m$

(b) Test Conditions: $P_m \leq 0.9\ S_y$

(c) Abnormal Conditions - Upset: See 4 and 5 below

- Faulted: $P_m \leq 0.7\ S_u$ or $2.4\ S_m$, whichever is lower

2. Primary Local Membrane Stress Intensity: P_L

(a) Design Conditions: $P_L \leq 1.5\ S_m$

(b) Test Conditions: $P_L \leq 1.35\ S_y$

(c) Abnormal Conditions - Upset: See 4 and 5 below

- Faulted: $P_L \leq 1.5 \times 0.7\ S_u$ or $1.5 \times 2.4\ S_m$, whichever is lower

3. Primary Membrane + Bending: $(P_L + P_b)$

(a) Design Conditions: $(P_L + P_b) \leq 1.5\ S_m$

(b) Test Conditions: $(P_L + P_b) \leq 1.35\ S_y$

(c) Abnormal Conditions - Upset: See 4 and 5 below

- Faulted: $(P_L + P_b) \leq 1.5 \times 0.7\ S_u$ or $1.5 \times 2.4\ S_m$, whichever is lower

4. Range of Primary + Secondary Stress Intensities: $(P_L + P_b + Q)$

$(P_L + P_b + Q)$ range for all normal and upset conditions: $\leq 3\ S_m$

5. Range of Total Stress Intensities: $(P_L + P_b + Q + F)$

Cumulative fatigue usage factor for all normal and upset conditions: < 1.0

6.2.5 LOADING CONDITIONS EVALUATED

The loading conditions considered in this analysis are as defined in Appendix B. These are specified below.

1. Design Conditions

Applicable Design Conditions are specified as:

a. Primary Side Design Conditions

P = 2485 psig

T = 650°F

b. Secondary Side Design Conditions

P = 1000 psig

T = 550°F

Case 1a, above, will govern the minimum wall thickness requirement in accordance with the ASME Code. [

]a,c,e Cladding is added over and above the minimum base metal.

2. Full load steady state conditions are:

Primary side pressure = 2235 psig
Hot leg temperature = 604°F
Cold leg temperature = 550°F
Secondary side pressure = 870 psig
Feedwater temperature = 435°F
Steam temperature = 520.3°F

3. Other specified loading conditions are:

Design, Faulted, Upset, and Test Conditions - Table 6.2-5

Transient Conditions - Table 6.2-6

Abnormal Conditions - Table 6.2-7

Pressure Test Conditions - Table 6.2-8

6.2.6 METHODS OF ANALYSIS

6.2.6.1 Model Development

Finite element models were developed for evaluating the HEJ* sleeve configuration shown in Figures 6.2-2 and 6.2-3. To avoid computational problems of a large model, the upper joint and the lower joint were modeled separately. The base module in the axial direction was kept at [ ]a,c,e thick in order to preclude difficulties with the large aspect ratios in the elements. The clad portion was further divided into 3 elements in each module, as seen in Figure 6.2-4. The upper joint model is shown in Figures 6.2-5 and 6.2-6, while the lower joint model is depicted in Figures 6.2-7 and 6.2-8. The base tubesheet module is shown in Figure 6.2-9. Some significant considerations in developing the model were:

*HEJ = Hybrid Expansion Joint.

1. The nodes along the roll expanded tube/sleeve zone were coupled in the radial direction for both the thermal and stress analyses. In addition, an axial coupling was effected at one shoulder of that zone for the upper joint. This coupling was done at the bottom elements of the lower joint.

2. An air gap was included below the joint between the tube and the sleeve. Although this space could be filled with secondary fluid in the event of a degraded tube, assuming the physical properties of air for these elements would be more conservative for the thermal stress analysis.

3. By changing the pressure loading at a specified region and the constraints of the model, the conditions of either an intact tube or discontinuous tube were simulated.

4. A hydraulically expanded zone not further mechanically expanded was also assumed to be coupled to the tube ID.

5. For the primary stress evaluation, the clad elements were nullified per ASME Section NB-3122.1 This was achieved by setting the modulus of elasticity equal to zero for the clad material and using proper nodal couplings between the sleeve OD and tube ID. Of course, these elements were restored in the $3S_m$ stress intensity range and the fatigue evaluations required per NB-3122.3.

The finite element type chosen for the analysis was the WECAN[1] element, STIF53, "Isoparametric 2-Dimensional Quadrilateral." Most of the elements are mixed quadratic, having a single node placed in the center of each edge in addition to the corner nodes. The tube and sleeve model elements are cubic, 2 nodes at the edges adjacent to the cladding element, which have corner nodes only.

6.2.6.2 Thermal Analysis

The purpose of the thermal analysis is to provide the temperature distribution needed for thermal stress evaluation. Since the thermal stress solutions are used for the fatigue evaluation, the maximum range of stress intensities during any of the loading conditions considered is to be calculated. The transient conditions in Tables 6.2-6 and 6.2-7 may be categorized by fluid temperature fluctuations and temperature rate changes. The transient conditions with higher temperature fluctuations and/or rates of temperature change will induce more extensive or higher thermal stresses. The transients may be further categorized into conditions resulting in an increase in primary fluid temperature and conditions which result in a decrease in primary fluid temperature. An evaluation of the categorized transients resulted in the determination of "umbrella" transients. The "umbrella" transients chosen for detailed thermal analysis and the transients they cover are shown in Table 6.2-14. In previous thermal transient runs done on tube sleeves, it was observed that the temperature responses did closely follow the variations of the boundary temperature. Thus, it was unnecessary to perform time history thermal analyses.

The remaining transients had very low fluid temperature change rates and were also considered through a steady state condition thermal analysis. The 19 thermal cases evaluated are listed in Table 6.2-15.

All thermal analyses were performed using the WECAN[1] model described in Figures 6.2-4 through 6.2-9. Elements were supplied to simulate the medium between the tube and the sleeve. The finite element type chosen for the thermal analysis was STIF58, "2D Isoparametric Quadrilateral Heat Conduction". In order to perform the WECAN thermal analysis, boundary conditions consisting of fluid temperatures and convective heat transfer coefficients for the corresponding element surfaces were needed. Two methods were used in calculating the boundary conditions. For steady state conditions, the computer code GENF[2] was used to provide steady state fluid temperatures and film coefficients for the primary and secondary side of the WECAN model. For transient conditions, conservative primary and secondary fluid conditions were developed for the three umbrella transients and evaluated as equivalent steady state conditions.

The heat transfer coefficients used in the analysis were calculated in the following manner:

1. Primary (inside) surface of tube[3]:

<u>Colburn's Equation</u> $$h_i = \frac{k}{D_i} 0.023(R_e)^{0.8}(P_r)^{0.333}$$

where:

h_i = film coefficient, Btu/ft^2-hr-°F

D_i = inside diameter, ft.

R_e = Reynolds No. = $\frac{\dot{m}_i D_i}{\mu A_i}$

P_r = Prandtl No. = $C_p \mu / k$

k = fluid conductivity, Btu/ft-hr-°F

A_i = inside flow area, ft^2

μ = fluid viscosity, lbm/hr-ft

$\dot{m}$ = primary flow rate, lbm/hr

C_p = specific heat, Btu/lbm-°F

2. Secondary (outside) surface of tube[4]:

For quasi-steady state heat transfer:

$$q = U_o A_T \Delta T$$

where: q = total heat transfer, Btu/hr

U_o = outside overall heat transfer coefficient Btu/ft^2-hr-°F

A_T = total outside heat transfer area, ft^2

ΔT = temperature difference of inside and outside fluids, °F

6.2.6.3 Stress Analysis

The WECAN models described in Subsection 6.2.6.1 were used to determine the stress levels in the tube/sleeve configuration including the rolled transition region for both the pressure and the temperature loading conditions. It is pointed out that the clad elements were restored in the models for these runs. Because this was a linear elastic analysis, thermally induced and pressure induced stresses were calculated separately and then combined to calculate the total stress distribution using computer program WECEVAL (4). In addition, WECEVAL was used to obtain the stress categorization required for an ASME Boiler and Pressure Vessel Code - Section III stress evaluation including complete fatigue evaluation. The criteria used in the evaluation was that specified in Subsection NB of the ASME Boiler and Pressure Vessel Code, Section III.

(A) Pressure Stress Analysis

For superposition purposes, the WECAN models were used to determine stress distributions induced separately by a 1000 psi primary pressure and a 1000 psi secondary pressure. The results of these "unit pressure" runs were then scaled to the actual primary side and secondary side pressures corresponding to the loading conditions considered in order to determine the total pressure stress distribution. As mentioned previously, the modeling considerations in determining the unit pressure load stress distributions were tube intact or tube discontinuous.

Therefore, the following unit pressure loading conditions were evaluated to determine the maximum anticipated stress levels induced by primary and secondary pressures in both the upper and lower joints:

1. Primary Pressure-Tube Intact

2. Primary Pressure-Tube Discontinuous

3. Secondary Pressure-Tube Intact

4. Secondary Pressure-Tube Discontinuous

The boundary conditions applied to the WECAN models for each of the unit pressure loading conditions are presented in Figures 6.2-10 through 6.2-13.

The end cap pressures shown at the top of the model are due to the axial pressure stress induced in the tube away from discontinuities and are calculated as follows:

$$\sigma_p = F_p/A = R_i^2 \times \pi \times 1000 / \pi(R_o^2 - R_i^2) \text{ for primary pressure}$$

and

$$\sigma_s = F_s/A = R_o^2 \times \pi \times 1000 / \pi(R_o^2 - R_i^2) \text{ for secondary pressure}$$

where:
σ_p = Primary pressure end cap pressure load, psi.
F_p = Primary pressure end cap force, lbs.
R_i = Inside radius of tube, in.
R_o = Outside radius of tube, in.
σ_s = Secondary pressure end cap pressure load, psi.
F_s = Secondary pressure end cap force, lbs.

For assumed dented conditions, the end cap load is not required. When the tube is discontinuous, the end cap load is transferred to the sleeve for the lower joint analysis.

The pressure loadings associated with each steady state or transient condition considered are summarized in Table 6.2-9.

(B) Thermal Stress Analysis

The WECAN models were used to determine the stress levels in the tube/sleeve configuration that are induced by the temperature distributions calculated by the thermal analysis. Each of the steady state conditions is evaluated. The thermal boundary conditions used in the analysis are schematically represented in Figure 6.2-14.

(C) Combined Pressure + Thermal Stress Evaluation

As mentioned previously, total stress distributions were determined by combining the unit pressure and thermal stress results as follows:

$$\sigma_{total} = \frac{P_{pri}}{1000} \times (\sigma)_{unit\ primary\ pressure} + \frac{P_{sec}}{1000} \times (\sigma)_{unit\ secondary\ pressure} + (\sigma)_{thermal}$$

At any given point or section of each model, the program WECEVAL can determine the total stress distribution for a given loading condition and categorize that total distribution per the Subsection NB requirements. That is, the total stress of a given cross-section through the thickness is categorized into membrane, linear bending, and non-linear components. These categorized stresses can then be compared to Subsection NB allowables. In addition, when supplied with a complete transient history at a given location in the model, program WECEVAL will calculate the total cumulative fatigue usage factor per Code Paragraph NB-3216.2. For the fatigue evaluation, the effect of local discontinuities must be considered. The WECAN model is refined sufficiently to include the effects of local discontinuities at all locations.

6.2.7 RESULTS OF ANALYSIS

Analyses were performed for both the hybrid expansion (HEJ) or upper joint and the lower joint configurations. Both intact as well as discontinuous tubes were considered. Fatigue and stress analyses of the sleeved tube assemblies for a [ ]^{a,b,e} sleeve have been completed in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section III. Critical sections for code stress evaluation and critical points for fatigue evaluation were identified and are presented in Figures 6.2-2 and 6.2-3.

6.2.7.1 Primary (Pressure) Stresses

The maximum primary (pressure) stresses for the analysis sections are summarized in Tables 6.2-11 and 6.2-12 in conjunction with the legend in Table 6.2-10. All primary stresses for the sleeved tube assemblies are well within allowable ASME Code stresses. The maximum primary stresses in the upper joint proper and the lower joint proper are tabulated in Table 6.2-13. The primary hydro test results in the highest primary stress intensity in the four tube/sleeve configurations analyzed. The minimum stress intensity margin is [ ]^{a,c,e} percent relative to the Code allowable and occurs in the sleeve. See Table 6.2-13C.

Figures 6.2-15, 6.2-16, and 6.2-17 depict the final design configuration. By comparing the R_m/t for the model and the design configuration, it is seen that the R_m/t for the design is slightly smaller [ ]^{a,c,e}. The clad material was ignored in determining R_m/t. It is concluded that the primary pressure stress intensity for the design configuration will be smaller [ ]^{a,c,e} than that calculated from the model.

6.2.7.2 Range of Primary and Secondary Stress Intensities

The maximum range stress intensity values for the sleeved tube assemblies are summarized in Tables 6.2-17a, 6.2-17b, 6.2-17c, and 6.2-17d in accordance with the legend shown in Tables 6.2-16a and 6.2-16b. The requirements of the ASME

Code, Paragraph NB-3222.2, were met directly at all locations and required no further consideration.

For the four sleeved tube configurations analyzed, Table 6.2-17e presents a summary of the maximum stress intensity range with its location in the component and the available margin to the allowable stress. [

]a,c,e

6.2.7.3 Range of Total Stress Intensities

Based on the sleeve design criteria presented in Section 3.1, the fatigue analysis considered a design life objective of 35 years for the sleeved tube assemblies. Tables 6.2-6 through 6.2-9 describe the transient conditions considered in the fatigue analysis. Since these tables provide transients for a 40-year design life objective, the values used in the fatigue analysis were 35/40 of these values. The transients are also listed in Table 6.2-15. A fatigue strength reduction factor of 5.0 was included for the hoop stress only. This highly conservative approach was taken in order to account for any stress magnification due to [

]a,b,c,e in the clad material. The results of the fatigue analysis for the sleeved tube assemblies are shown in Tables 6.2-18 through 6.2-21. All of the cumulative usage factors are below the allowable value of 1.0 specified in the ASME Code.

For the four sleeved tube configurations analyzed, [

]a,c,e The tube fatigue is negligible in all cases.

6.2.8 REFERENCES - SECTION 6.2

1. WECAN - Westinghouse Electric Computer Analysis, 79-IE7-NESPB-R5, Sept. 1979. (Proprietary)

2. WTD-PE-77-038 Rev. 1, "GENF: A Steady State Performance or Sizing Evaluation Code for Model F Steam Generators," P. J. Prabhu, Aug. 1978. (Proprietary)

3. Holman, J. P., Heat Transfer, McGraw-Hill Book Co., N. Y., 1968.

4. WECEVAL - WECAN Evaluation - Users Manual, Rev. 3, September, 1981, J. M. Hall, A. L. Thurman, J. B. Truitt NTD-SMD-ASA

TABLE 6.2-1

MATERIAL STRESS PROPERTIES FOR TUBE*

Temperature °F	Design Stress Intensity S_m, ksi	Yield Strength S_y, ksi	Ultimate Strength S_u, ksi
100	23.3	35.0	80.0
200	23.3	32.7	80.0
300	23.3	31.0	80.0
400	23.3	29.8	80.0
500	23.3	28.8	80.0
600	23.3	27.9	80.0
650	23.3	27.4	80.0

*Mill Annealed Alloy 600

TABLE 6.2-2

MATERIAL STRESS PROPERTIES FOR SLEEVE

Temperature °F	Design Stress Intensity(1) S_m, ksi	Yield Strength S_y, ksi	Ultimate Strength S_u, ksi
100	26.6	40.0	80.0
200	26.6	38.2	80.0
300	26.6	37.3	80.0
400	26.6	36.3	80.0
500	26.6	35.7	80.0
600	26.6	35.3	80.0
650	26.6	35.2	80.0

1. Refer to CASE OF ASME BOILER AND PRESSURE VESSEL CODE N-379 for material stress properties of Alloy 690 base material.

TABLE 6.2-3

MATERIAL STRESS PROPERTIES FOR CLAD[1]

Temperature °F	Design Stress Intensity S_m, ksi	Yield Strength S_y, ksi	Ultimate Strength S_u, ksi
100	36.6	60.0	120.0
200	36.6	60.0	120.0
300	36.6	60.0	120.0
400	35.7	60.0	120.0
500	34.8	60.0	120.0
600	33.9	60.0	120.0
650	33.5	60.0	120.0

1. Taken from the ASME Code III, Appendix I, S82, pp 32-33 for SB 444-625.

TABLE 6.2-4

MATERIAL STRESS PROPERTIES FOR TUBESHEET*

Temperature °F	Design Stress Intensity S_m, ksi	Yield Strength S_y, ksi	Ultimate Strength S_u, ksi
100	26.7	50.0	80.0
200	26.7	47.5	80.0
300	26.7	46.1	80.0
400	26.7	45.1	80.0
500	26.7	44.5	80.0
600	26.7	43.8	80.0
650	26.7	43.5	80.0

* Low alloy steel ASME SA 508, Class 2

TABLE 6.2-5

DESIGN, FAULTED, UPSET, AND TEST CONDITIONS

(Reference: Appendix B)

Conditions	Pressure Loading (psig) Primary	Secondary
Design	2485	1000
Faulted (MSLB)	2285	0
Faulted (LOCA)	0	1035
Upset: Loss of Flow	2265	885
Upset: Loss of Load	2405	885
Hydrotest, Primary 1.25 (2485)	3110	0
Hydrotest, Secondary 1.25 (1000)	0	1250
Leak Test Primary-to-Secondary	2285	0
Leak Test Secondary-to-Primary	0	870

TABLE 6.2-6

TRANSIENT CONDITIONS CONSIDERED

	Transient	No. of Occurrences[1]	Appendix B Curve No.
B1A	Plant Heatup	500	2
B1B	Plant Cooldown	500	2
B1C	Plant Loading	15,000	3
B1D	Plant Unloading	15,000	3
B1E	10 Percent Step Load Increase	2,000	4
B1F	10 Percent Step Load Decrease	2,000	4
B1G	Cold Feed Following Hot Standby	15,000	-
B1H	Steady State Fluctuation	10^6	-
B1I	Pump Start/Stop	4,000	-

(1) The number of occurrences shown here is for a 40-year design life.

TABLE 6.2-7

ABNORMAL CONDITIONS CONSIDERED

	Transient	No. of Occurrences(1)	Appendix B Curve No.
B2A	Reactor Trip (Upset)	400	5
B2B	Loss of Primary Flow (Upset)	40	6
B2C	Loss of Load (Upset)	40	7
B2D	Loss of Secondary Pressure (Emergency)	5	8
B2E	Addition of Feedwater (Emergency)	8	-

(1) 40-year design life

TABLE 6.2-8

PRESSURE TEST CONDITIONS CONSIDERED

	Transient	No. of Occurrences[1]	Appendix B Curve No.
B3A	Subsequent Primary Side Pressure Test	10	9
B3B	Subsequent Secondary Side Pressure Test	10	-
B3C	Primary to Secondary Leak Test (Upset)	200	10
B3D	Secondary to Primary Leak Test (Upset)	200	-

(1) 40-year design life

TABLE 6.2-9

PRESSURE LOADING SUMMARY

	Event	Pprimax, psig	Pprimin, psig	Psecmax, psig	Psecmin, psig
A.	Design Conditions	2485	0	1000	0
B1A.	Plant Heatup	2235	0	885	0
B1B.	Plant Cooldown	2235	0	885	0
B1C.	Plant Loading	2305	2235	853	800
B1D.	Plant Unloading	2305	2165	853	800
B1E.	10 Step Load Increase	2325	2235	805	800
B1F.	10 Step Load Decrease	2235	2165	805	800
B1G.	Hot Standby	2235	2235	885	885
B1H.	Steady State Fluctuations	2335	2135	840	760
B1I.	Pump Start/Stop	2320	2150	800	800
B2A.	Reactor Trip	2245	1745	885	800
B2B.	Loss of Flow	2265	1865	885	800
B2C.	Loss of Load	2405	1705	885	800
B2D	Loss of Secondary Pressure	2235	145	885	0
B2E	Addition of Feedwater	0	2235	0	0
B3A.	Subsequent Primary Side Pressure Tests	3110	0	0	0
B3B.	Subsequent Secondary Side Pressure Tests	0	0	1250	0
B3C.	Primary-to-Secondary Leak Tests	2485	0	235	0
B3D.	Secondary-to-Primary Leak Tests	165	0	985	0

TABLE 6.2-10

LEGEND TO TABULATED PRIMARY STRESS INTENSITY EVALUATION

Joint	Cutting[+] Section	Analysis Section No. (ASN) Sleeve	Tube
	Z-Z*	-	13
	A-A	6	12
	B-B	5	11
Upper	C-C	4	10
	Y-Y*	3	9
	D-D	2	8
	E-E*	1	7
	X-X*	6	12
	F-F	5	11
Lower	G-G	4	10
	H-H	3	9
	I-I	2	8
	W-W*	1	7

[+]See Subsection 6.2.1.1 of this report.

*These sections are of constant diameter.

TABLE 6.2-11a - n

MAXIMUM STRESS INTENSITIES IN THE TUBE/SLEEVE ASSEMBLY, UPPER JOINT

ASN*	P_m	S_m	$P_1 + P_b$	$1.5S_m$
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				

a,c,e

*Analysis Section Number

NOTE: All stress intensities in ksi.

TABLE 6.2-12a-2

MAXIMUM STRESS INTENSITIES IN THE TUBE/SLEEVE ASSEMBLY,
LOWER JOINT

ASN*	P_m	S_m	$P_l + P_b$	$1.5S_m$
1				a,c,e
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

*Analysis Section Number

NOTE: All stress intensities in ksi.

TABLE 6.2-13a-d

PRIMARY STRESS RESULTS

Condition	P_m Maximum (ksi)	P_m Allowable (ksi)	P_l+P_b Maximum (ksi)	P_l+P_b Allowable (ksi)
Design	a,c,e	(Sm)	a,c,e	(1.5Sm)
Sleeve		26.60		39.90
Tube		23.30		34.95
Faulted (Loss of secondary pressure)		(0.7Su) or (2.4 Sm)		(1.05Su) or (3.60 Sm)
Sleeve		56.00		84.00
Tube		55.92		83.88
Faulted (loss of primary pressure)		(0.7Su) or (2.4 Sm)		(1.05Su) or (3.60 Sm)
Sleeve		56.00		84.00
Tube		55.92		83.88
Upset (loss of flow)		(Sm)		(1.5Sm)
Sleeve		26.60		39.90
Tube		23.30		34.95
Upset (loss of load)		(Sm)		(1.5Sm)
Sleeve		26.60		39.90
Tube		23.30		34.95
Test (Primary Hydro)		(0.9Sy)		(1.35Sy)
Sleeve		32.67		49.01
Tube		26.82		40.23
Test (Secondary Hydro)		(0.9Sy)		(1.35Sy)
Sleeve		36.00		54.00
Tube		31.50		47.25

TABLE 6.2-14

GROUPING OF THERMAL TRANSIENTS

Transient	Represented

a,b,c

TABLE 6.2-15

TRANSIENTS FOR THE 35-YEAR LIFE

DESIGNATION*	INDEX	NOTATION	CYCLES
--	1	AMBIENT	437
B1A	2	HEATUP	437
B1B	3	COOLDOWN	437
B1C	4	LOAD	13125
B1D	5	UNLOAD	13125
B1H	6	SSFLUCT	87500
B1E	7	TENPCTUP	1750
B2B	8	LOSSFLOW	35
B2A	9	RTRIP	350
B2C	10	LOSSLOAD	35
B1F	11	TENPCTDN	1750
B2D	12	LOSSPRESS	4
B1G	13	HTSTDBY	13125
B2E	14	LSFEEDFLO	7
B3A	15	PRIMHYDRO	9
B3B	16	SECHYDRO	9
B3C	17	PRIMLEAK	175
B3D	18	SECLEAK	175
B1I	19	PUMPSTSTP	3500

*See Tables 6.2-6, 6.2-7, and 6.2-8

TABLE 6.2-16a

NODES IN THE $3S_m$ AND FATIGUE EVALUATIONS
(UPPER JOINT)

ASN*	Surface Inside	Surface Outside	
1	33	36	Sleeve
2	97	100	Sleeve
3	153	156	Sleeve
4	233	236	Sleeve
5	305	308	Sleeve
6	353	356	Sleeve
7	532	534	Tube
8	596	598	Tube
9	652	654	Tube
10	732	734	Tube
11	804	806	Tube
12	852	854	Tube
13	932	934	Tube

*Analysis Section Number

TABLE 6.2-16b

NODES IN THE $3S_m$ AND FATIGUE EVALUATIONS
(LOWER JOINT)

ASN*	Surface Inside	Surface Outside	
1	17	--	Sleeve
2	113	--	Sleeve
3	177	--	Sleeve
4	241	244	Sleeve
5	701	704	Sleeve
6	853	856	Sleeve
7	--	1518	Tube
8	--	1614	Tube
9	--	1678	Tube
10	1740	1742	Tube
11	2200	2202	Tube
12	2352	2354	Tube

*Analysis Section Number

TABLE 6.2-17a-d

MAXIMUM RANGE OF STRESS INTENSITY ANALYSIS,

ANALYSIS SECTION	SURFACE	LOAD CONDITION COMBINATION	SI RANGE (KSI)	ALLOWABLE (KSI)

a,b,c

4393Q:1/051783

TABLE 6.2-17e

SUMMARY OF MAXIMUM STRESS RANGE

		Upper Joint	Lower Joint
Tube Intact:			
Sleeve -	Maximum SR		
	Margin		
	ASN		
	Surface		
Tube -	Maximum SR		
	Margin		
	ASN		
	Surface		
Tube Discontinuous:			
Sleeve -	Maximum SR		
	Margin		
	ASN		
	Surface		
Tube -	Maximum SR		
	Margin		
	ASN		
	Surface		

a,b,c

TABLE 6.2-18a – Z

FATIGUE CALCULATIONS, UPPER JOINT, TUBE INTACT

MATERIAL = INCONEL / AUSTENITIC STEEL

LOAD COND COMB	USABLE CYCLES M	STRESS INTENSITY RANGE KE*K*SIJ (PSI)	ALTERNATING STRESS INTENSITY KE*K*SIJ/2 (PSI)	ALLOWABLE CYCLES N	USAGE FACTOR M/N

a,b,c

*This is the correction factor due to the difference in E used in the analysis and that used in the ASME fatigue curves.

TABLE 6.2-19a-z

FATIGUE CALCULATIONS, UPPER JOINT, TUBE DISCONTINUOUS,

MATERIAL = INCONEL / AUSTENITIC STEEL

LOAD COND COMB	USABLE CYCLES M	STRESS INTENSITY RANGE KE*K*SIJ (PSI)	ALTERNATING STRESS INTENSITY KE*K*SIJ/2 (PSI)	ALLOWABLE CYCLES N	USAGE FACTOR M/N

a,b,c

*This is the correction factor due to the difference in E used in the analysis and that used in the ASME fatigue curves.

TABLE 6.2-20a - r

FATIGUE CALCULATIONS, LOWER JOINT,
TUBE INTACT

MATERIAL = INCONEL / AUSTENITIC STEEL

LOAD COND COMB	USABLE CYCLES N	STRESS INTENSITY RANGE KE*K*SIJ (PSI)	ALTERNATING STRESS INTENSITY KE*K*SIJ/2 (PSI)	ALLOWABLE CYCLES N	USAGE FACTOR N/N

a, b, c

*This is the correction factor due to the difference in E used in the analysis and that used in the ASME fatigue curves.

TABLE 6.2-21a-r

FATIGUE CALCULATIONS, LOWER JOINT

TUBE DISCONTINUOUS

MATERIAL = INCONEL / AUSTENITIC STEEL

LOAD COND COMB	USABLE CYCLES n	STRESS INTENSITY RANGE KE*K*SIJ (PSI)	ALTERNATING STRESS INTENSITY KE*K*SIJ/2 (PSI)	ALLOWABLE CYCLES N	USAGE FACTOR n/N

a,b,c

*This is the correction factor due to the difference in E used in the analysis and that used in the ASME fatigue curves.

TABLE 6.2-22a-d

FATIGUE USAGE SUMMARY

ASN*	Surface Inside	Surface Outside
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		

a,b,c

* Analysis Section Number

a, c, e, f

Figure 6.2-1. Millstone Sleeve Geometry

Figure 6.2-2 Millstone Sleeve Geometry at Upper Joint
FOR ANALYSIS

Figure 6.2-3. Millstone Sleeve Geometry at Lower Joint
FOR ANALYSIS

Figure 6.2-4 Base Module of Upper Joint Model

Figure 6.2-5 Upper Joint Model, Top Portion

Figure 6.2-6 Upper Joint Model, Bottom Portion

Figure 6.2-7 Lower Joint Model, Top Portion

Figure 6.2-8. Lower Joint Model, Bottom Portion

6.2-166 TO 6.2-173

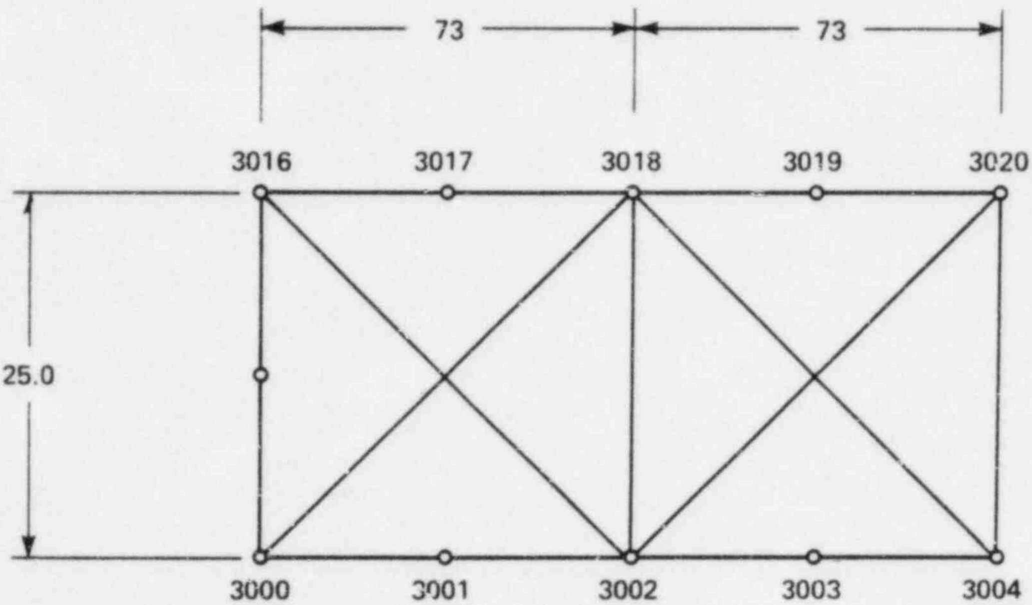


Figure 6.2-9 Base Module of Tubesheet Model

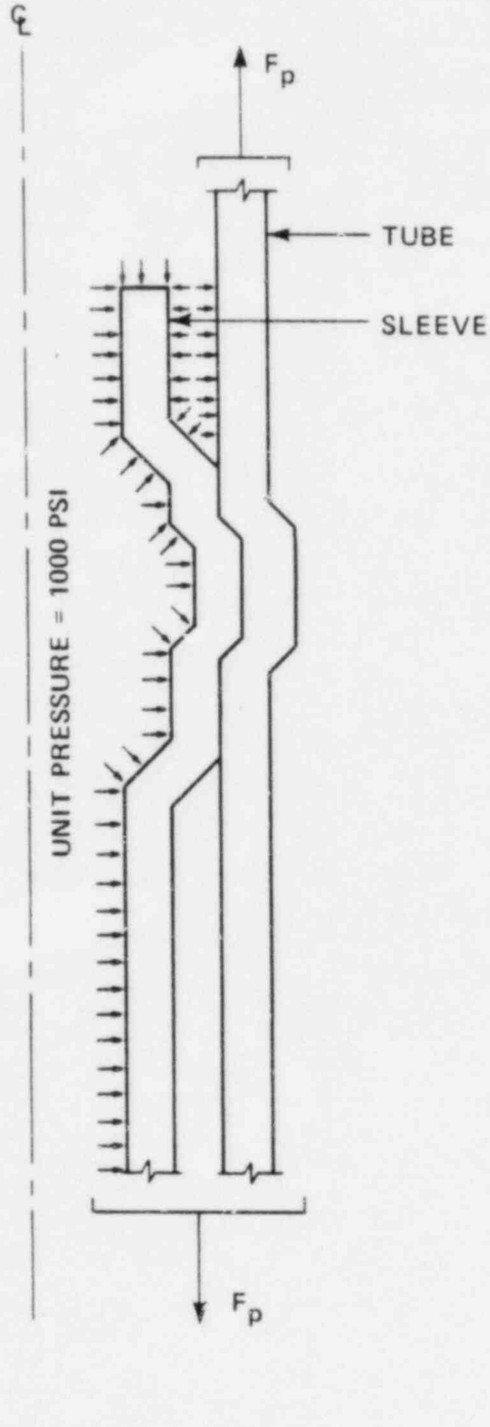


Figure 6.2-10 Boundary Conditions for Hybrid Expansion Joint, Unit Primary Pressure, Tube Intact

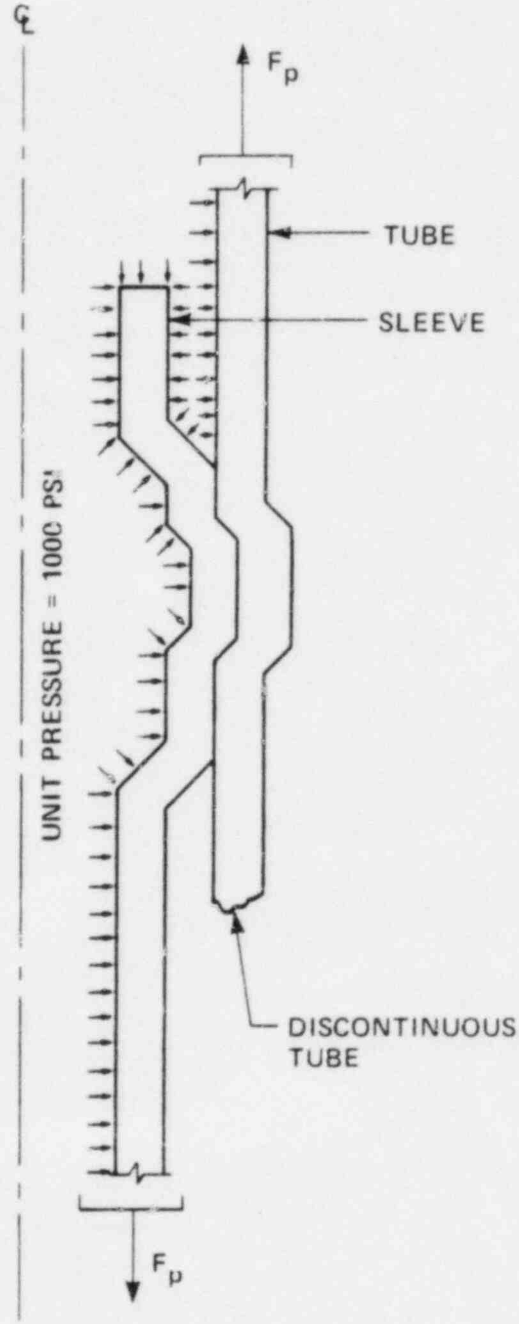


Figure 6.2-11 Boundary Conditions for Hybrid Expansion Joint,Unit Primary Pressure,Tube Discontinuous

4092-11

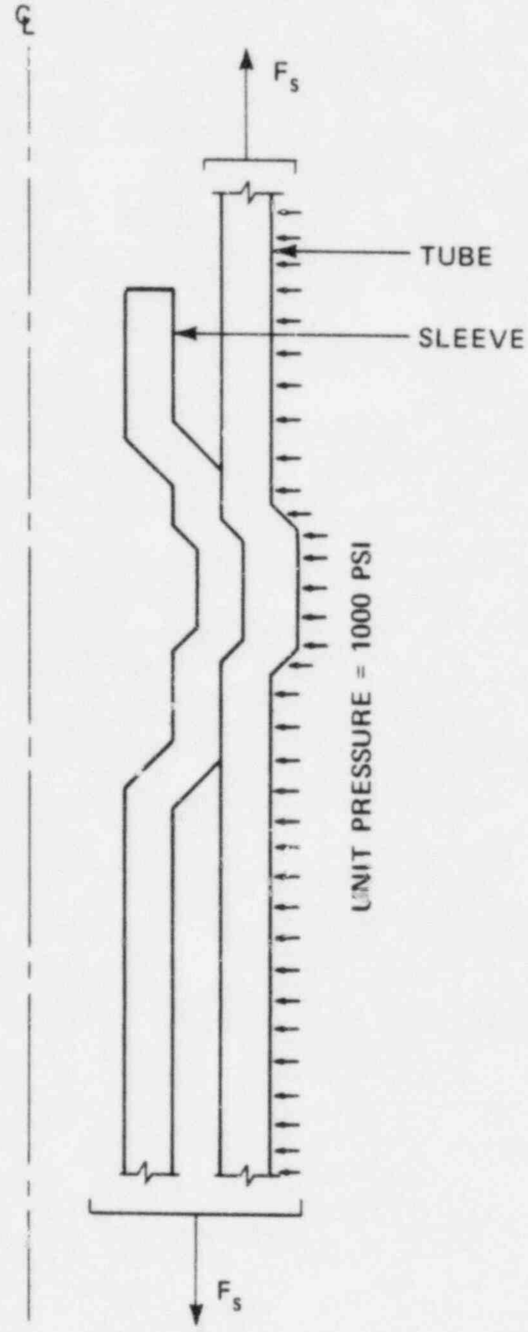


Figure 6.2-12 Boundary Conditions for Hybrid Expansion Joint, Unit Secondary Pressure, Tube Intact

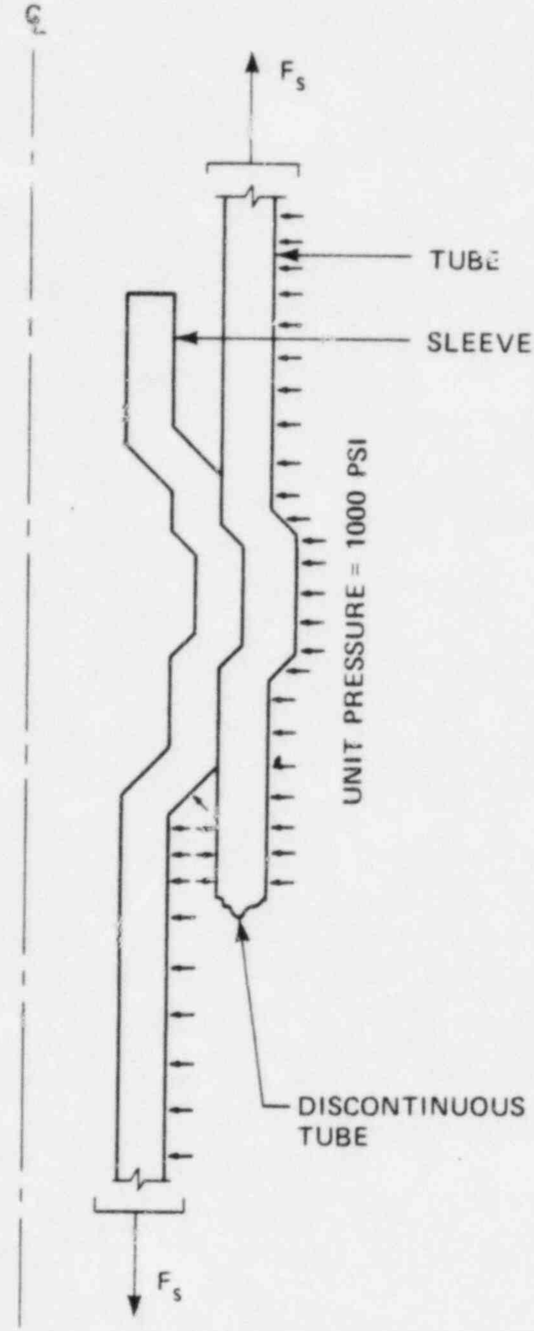
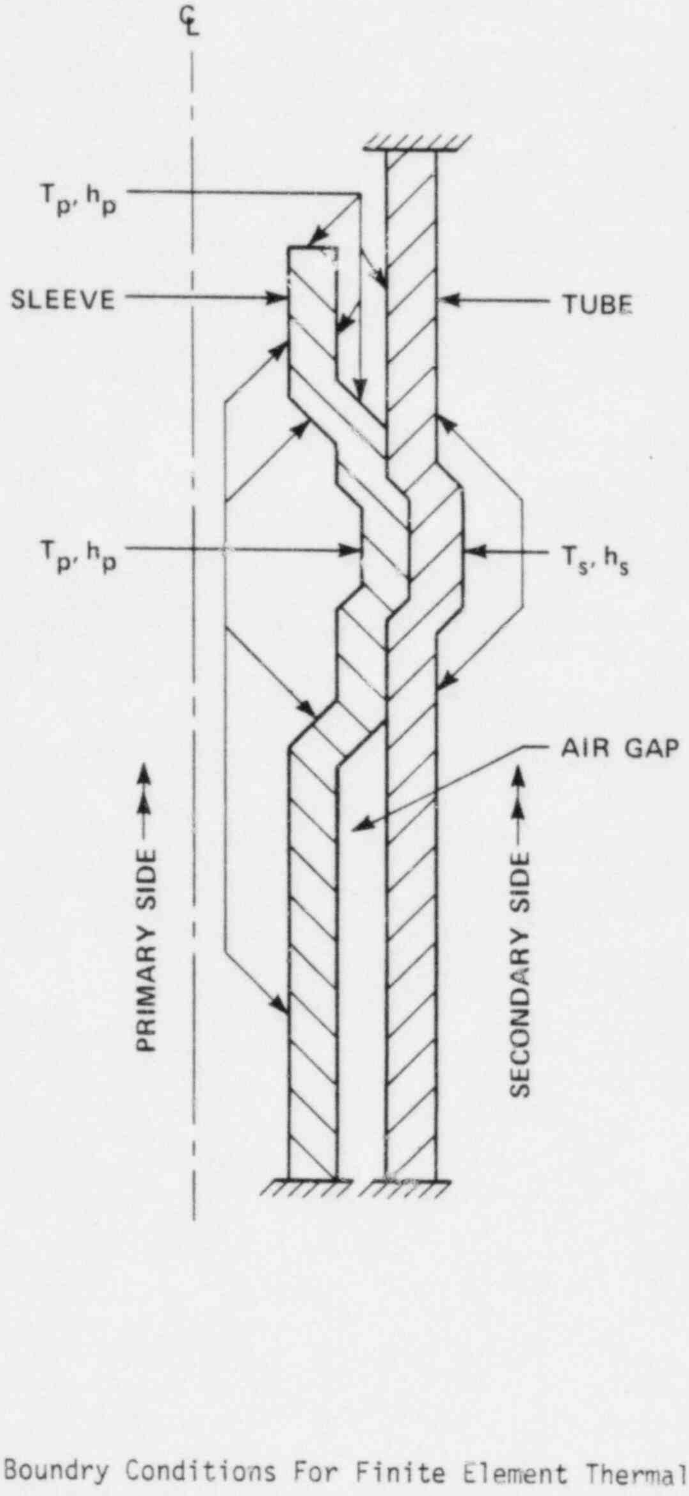


Figure 6.2-13 Boundary Conditions for Hybrid Expansion Joint, Unit Secondary Pressure, Tube Discontinuous

4092-13



T_p = PRIMARY SIDE FLUID TEMP.

T_s = SECONDARY SIDE FLUID TEMP.

h_p = PRIMARY SIDE FILM COEFF.

h_s = SECONDARY SIDE FILM COEFF.

Figure 6.2-14 Boundry Conditions For Finite Element Thermal Analysis

a, c, e, f

Figure 6.2-15. Upper Joint (HEJ) Nominal Configuration

Figure 6.2-16. Lower Joint Nominal Configuration

Figure 6.2-17. Nominal Dimensions – Bimetal Sleeve

6.3 SPECIAL CONSIDERATIONS

6.3.1 THERMAL EFFECTS OF SLUDGE

Previous analyses of the thermal effects of various sludge heights have shown the following:

[ ] a,c,e

The foregoing discussion is for the model with air in the annular gap between the sleeve and the tube. Where a tube discontinuity is postulated and caustic is assumed to fill the annular gap, the thermal gradient curve will lie between that of the step change for the sleeveless case and that for the air-in-the-gap case. [

]a,c,e

6.3.2 ALLOWABLE SLEEVE DEGRADATION

Minimum sleeve wall thickness, t_r, to sustain normal and accident condition loads are calculated in accordance with the guidelines of Regulatory Guide 1.121. In this evaluation, the surrounding tube is assumed to be completely degraded; that is, no credit is taken for the strength of the tube.

The nominal sleeve is [
]^{a,c,e} cladding on the OD. Thus,

[ ]^{a,c,e}

Max. $R_i = R_{i\ max} - t_{min}$

= [ ]^{a,c,e}

The sleeve material is thermally treated Inconel 690. The allowable stress limit is based on the following code minimum properties at 600°F:

S_m = 26.6 ksi
S_u = 80.0 ksi
S_y = 35.3 ksi

Regulatory Guide 1.121 Criteria

(1) Normal Operation

Determine t_r, minimum sleeve wall thickness.

Criterion: $P_m \leq 35.3$ ksi
Loading: P_p = 2250 psia
P_s = 885 psia ΔP = 1365 psi

Hence, $t_r = \frac{\Delta P \quad R_{i\ max}}{Sy - 0.5\ (P_p + P_s)}$

$= [\frac{1365 \times 0.273}{35{,}300 - 0.5\ (2250 + 885)}]^{a,c,e} = 0.0110$ inch

which is [25.3][a,c,e] percent of the nominal wall thickness.

(2) Accident Condition Loadings

a. LOCA + SSE

The major contribution of LOCA and SSE loads is the bending stresses at the top tube support plate due to the support motion, inertial loadings, and the pressure differential across the tube U-bend resulting from the rarefaction wave during LOCA. Since the sleeve for Millstone 2 application is located below the first support, the LOCA + SSE bending stresses in the sleeve are quite small. The governing event for the sleeve therefore is a postulated secondary side blowdown.

b. MSLB + SSE

The maximum primary-to-secondary pressure differential occurs during a postulated steamline break (MSLB) accident. Again, because of the sleeve location, the SSE bending stresses are small. Thus, the governing stresses for the minimum wall thickness requirement are the pressure membrane stresses.

Criterion: $P_m \leq$ smaller of $0.7S_u$ or $2.4S_m$; i.e., 56.0 ksi

Loadings: P_p = 2285 psig (Ref: Appendix B, Table V)
$P_s \cong 0$ psig ΔP = 2285 psi

$$\text{Hence, } t_r = \frac{\Delta P \quad R_{i\,max}}{0.7Su \quad -0.5\,(P_p + P_s)}$$

$= [\qquad\qquad\qquad\qquad]^{a,c,e} = 0.0114$ inch

or, $[\qquad\qquad\qquad\qquad]^{a,c,e}$ of nominal wall

(3) Leak-Before-Break Verification

The rationale behind this requirement is to limit the maximum allowable (primary-to-secondary) leak rate during normal operation such that the associated crack length (through which the leakage occurs) is less than the critical length corresponding to the maximum postulated accident condition pressure loading. Thus, on the basis of leakage monitoring during normal operation, it is assured that an unstable crack growth leading to tube rupture would not occur in the unlikely event of the limiting accident.

For the Millstone Unit 2, the maximum Technical Specification allowable leak rate is 0.5 gpm per steam generator. Leak test data available for Westinghouse Model D steam generators is the closest possible data base which may be used for the Millstone 2 sleeve. The results are adjusted for parametric differences. Figure 6.3-1 shows results from base data and adjusted results for Millstone 2 sleeve conditions. From this figure it may be observed that the axial crack length size L for the sleeve is $[\qquad]^{a,c,e}$ for the maximum allowable Technical Specification limit of 0.5 gpm. This must be less than the critical length for worst accident condition loading.

Critical crack length L_c is obtained by using Hahn's relationship[3] as indicated below:

$$\text{Burst hoop stress } \sigma_\theta = \frac{\bar{\sigma}}{(1 + 0.4025\,\lambda^2)^{0.5}}$$

where:

$$\sigma_t = \frac{P R_m}{t}$$

$\bar{\sigma}$ = Flow stress, assumed here as 0.5 $(S_y + S_u)$, psi

λ = Normalized crack length = $\frac{L}{\sqrt{R_m t}}$

P = Burst pressure, psi

R_m = Mean radius = [0.294 inch]^{a,c,e}

t = Wall thickness = [0.0435 inch]^{a,c,e}

S_y = Yield strength, ksi

S_u = Ultimate strength, ksi

Lower tolerance limits for yield and ultimate strengths are obtained from a set of six tensile test data. These values at room temperature are [ ]^{a,c,e}, respectively. Projected values at 650°F are obtained on the basis of trends observed for Inconel 600 in the ASME Code. The values for Sy and Su at 650°F are obtained as [ ]^{a,c,e}, respectively.

The maximum ΔP condition is 2285 psi which occurs during a main steam line break (MSLB). Substituting the values in Hahn's equation, the critical λ_c is obtained as [ ]^{a,c,e} and the critical crack length L_c as [ ]^{a,c,e}. Since this is greater than the crack length of [ ]^{a,c,e} corresponding to the maximum Technical Specification leak limit of 0.5 gpm, "leak-before-break" condition is verified.

(4) Margin To Burst Under Normal ΔP

In Regulatory Guide 1.121, the NRC has taken the position that a factor of safety (FS) of 3 should be a goal against bursting under the normal operating pressure differential. However, Westinghouse has taken exception to this position, and instead, used FS = 2 in addition to the requirement that the burst pressure be greater than the maximum postulated accident condition pressure differential.*

Maximum allowable axial crack length not exceeding the Technical Specification leak limit of 0.5 gpm under normal operating conditions has been evaluated to be [

]a,c,e as shown in Figure 6.3-2 (Hahn's curve) which is a nondimensionalized graphical presentation of Hahn's equation.

In the range of interest (for relatively low values of λ), this curve generally falls below burst test data for Inconel 600 tubes. A representative burst test data for an uncracked ($\lambda = 0$) bimetallic Inconel 690/625 sleeve is plotted in the figure. The data is shown to fall somewhat above the Hahn curve of Figure 6.3-2 indicating that this curve may also be used to obtain burst pressures for Inconel 690/625 bimetal sleeves with reasonable accuracy. The burst

*Westinghouse has documented its opinion and position on this requirement by corporate letter NS-CE-1282 (dated 11/22/76) and Section 3A of RESAR 414 FSAR.

pressure corresponding to [
]^{a,c,e} for the sleeve. Therefore, the factor of safety against burst during normal operating conditions is given by:

$$\text{Factor of Safety} = \frac{\Delta P_{burst}}{\Delta P_{operating}} = \frac{[\quad]^{a,c,e}}{1365} = [\quad]^{a,c,e}$$

which is greater than 2 (Westinghouse position). A factor of safety of at least 2 against burst during normal operations is maintained for a through-wall defected sleeve.

6.3.3 EFFECT OF TUBESHEET/SUPPORT PLATE INTERACTION

Since the pressure is normally higher on the primary side of the tubesheet than on the secondary side, the tubesheet becomes concave upward. Under this condition, the tubes protruding from the top of the tubesheet will rotate from the vertical. This rotation depends on the boundary condition for the edges of the tubesheet.

In assessing the case for the Millstone 2 tubesheet, data was taken from the Westinghouse finite element analysis of a similar geometry using a simple axisymmetric model. After an adjustment for tubesheet geometry and the ΔP across the tubesheet, a maximum tube rotation was computed to be:

$$\theta_{max} = [\qquad]^{a,c,e}$$

(for $t = 21.5$ inches and $\Delta P = 1365$ psi)

If the tube is assumed fixed at the first tube support crate, the bending moment in the tube is found by

$$m_{\theta\ max} = \frac{4\ EI}{L}\ \theta_{max}$$

and

$$\sigma_{max} = \frac{MC}{I} = \frac{4\ EC}{L}\ \theta_{max}$$

For $L = 28.00$ inches and $E = 29.2 \times 10^6$ psi,

$C = [0.3155]^{a,c,e}$ inch for the sleeve

$= [0.375]^{a,c,e}$ inch for the tube

[ ]a,c,e

These stresses are not large enough to affect significantly the fatigue usage factors already found.

6.3.4 EVALUATION OF OPERATION WITH FLOW EFFECTS DUE TO SLEEVING

The operational effect analysis of the sleeving repair in this report is limited to an evaluation of the increase in the primary side tube pressure drop due to the sleeve installation. The installation of a sleeve into a tube adds an additional flow restriction with an associated increase in pressure drop. This increase in pressure drop may be calculated from the equation:

$$\Delta p = (K_z + K_\varepsilon)\ \frac{\rho V^2}{2g}$$

where K_z is the pressure drop loss coefficient of the unsleeved tube and K_ε is the change in the coefficient due to the addition of a sleeve in the hot or cold leg or both. These loss coefficients have been determined to be:

[ ]a,c,e

A special safety study has previously been submitted to the NRC by Northeast Utilities and approved for use at Millstone 2 evaluating the effects of reduced RCS flow in the steam generators. This safety study analyzes the effects of up to a maximum of 2500 tubes plugged in the two steam generators on the core cooling capability under various plant conditions. Evaluation of the effects of the sleeve program on this safety study is the responsibility of Northeast Utilities.

6.3.5 EFFECT OF PRE-BOWING FOR AUTOMATIC INSTALLATION

The effect of introducing a slight bow to the sleeve for automatic installation purposes is that it will introduce some small initial residual stress to the sleeve. There is no impact of this residual stress on primary stress intensity, primary plus secondary stress intensity range for racheting, or total stress intensity range for fatigue evaluation. Essentially, residual stress may be treated as fabrication induced stress and does not need any specific evaluation for satisfaction of ASME Section III Code limits.

6.3.6 COMPARATIVE BENDING STRENGTH OF THE SLEEVE AND A DEGRADED TUBE

The bending strengths of the sleeve and steam generator tube are evaluated by comparing their moment carrying capacities.

Dimensions of the sleeve are taken from Figure 6.2-17. Code minimum properties of the tube and sleeve materials at 600°F are utilized, with the design allowables for the sleeve conservatively taken as those of the sleeve base material only.

The sleeve is taken as having an [
][a,c,e]

[ ][a,c,e]

A tube detected by eddy current to be degraded to the 40 percent plugging limit is actually taken as a 50 percent degraded tube in this analysis to account for 10 percent uncertainty in the eddy current testing. Thus, the steam generator tube will have a [
][a,c,e]

[ ][a,c,e]

For bending strength comparisons, the moment carrying capacity for both the tube and the sleeve are computed at 600°F using Code minimum properties.

$$M = \delta_a S$$

where:

M	=	moment carrying capacity
δ_a	=	$1.5\ S_m$
δ_{at}	=	1.5 x 23.3 = 34.95 ksi for the tube
δ_{as}	=	1.5 x 26.6 = 39.90 ksi for the sleeve
S	=	appropriate section modulus

[ ]a,c,e

Finally,

$$\frac{M_s}{M_t} = \frac{0.4405}{0.2928} = 1.504$$

The bending strength ratio of the sleeve to the 50 percent degraded tube is [ ]a,c,e stronger than the 50 percent degradea tube.

6.3.7 REFERENCES - SECTION 6.3

1. Hirst, C. W., et. al., "Analytical and Experimental Evaluation of the Mechanical Integrity of Steam Generator Tubing," WCAP-8429 (Westinghouse Proprietary), Westinghouse Nuclear Energy Systems, Pittsburgh, PA, June 1981.

2. Vagins, M., et. al., "Steam Generator Tube Integrity Program - Phase I Report," NUREG/CR-0718, September 1979.

3. Hahn, G. T., et. al., "Criteria for Crack Extension in Cylindrical Pressure Vessels," Intl. J. Fracture Mech., Vol., 5, 1969.

a,b,c,e

Figure 6.3-1 LEAK RATE vs CRACK LENGTH

[ ]a,b,c,e

Figure 6.3-2 NORMALIZED BURST PRESSURE vs AXIAL CRACK LENGTH

7.0 NDE INSPECTABILITY

The NDE development effort is concentrated on two aspects of the sleeve system. First, consideration is being given to a method of showing that the joints meet the design objectives. Secondly, it must be shown that the tube/-sleeve assembly is capable of being evaluated through subsequent routine in-service inspection. In both of these efforts, the inspection process has relied upon eddy current technology.

7.1 EDDY CURRENT INSPECTIONS

The eddy current inspection equipment, techniques, and results presented in this section apply to the sleeving process used in steam generators at Indian Point Unit 3. Similar techniques have been developed for application in the steam generators at Millstone Unit 2 using the sleeving processes described in Section 4. The bimetallic sleeve has no unique impact on the inspectability of the sleeve/tube assembly. Techniques to be utilized for bimetallic sleeves are equivalent or improved upon from previous sleeving programs.

Eddy current inspections are routinely carried out on the nuclear steam generators at Millstone Unit 2 in accordance with the Technical Specifications. The purpose of these inspections is to detect at an early state tube degradation that may have occurred during plant operation so that corrective action could be taken to minimize further degradation and reduce the potential for significant primary-to-secondary leakage.

The standard inspection procedure involves the use of an eddy current probe with two circumferentially wound coils which are displaced axially along the probe body. The coils are connected in the so-called differential mode; that is, the system responds only when there is a difference in the properties of the material surrounding the two coils. The coils are excited by using an eddy current instrument which displays changes in the material surrounding the coils by measuring the electrical impedance of the coils. In the past, eddy current instruments normally excited the coils at single frequency; however, Westinghouse and the industry are now using multi-frequency instrumentation

for the inspection of steam generator tubing. This involves simultaneous excitation of the coils with several different test frequencies.

The outputs of the various frequencies are both combined and recorded. The combined data yield an output in which signals resulting from conditions that do not affect the integrity of the tube are reduced. By reducing unwanted signals, improved inspectability of the tubing results. Regions in the steam generator, such as the tube supports or tube sheet, are examples of areas where multifrequency processing has proved valuable in providing additional inspectability techniques.

A number of eddy current probes and signal processing systems are available for the eddy current inspection of the tube/sleeve assembly. A few of the probes available are shown in Figure 7.1-1. In addition to the conventional probe and the rotating pancake coil (RPC), there is a cross-wound coil probe (CWC) and a multicoil surface riding probe (MSR). Any of these probes may be used with either single frequency or multifrequency instrumentation.

After sleeve installation, all sleeved tubes will be subjected to a series of eddy current inspections. Some of these inspections are intended only as a process control procedure to verify correct sleeve installation; others are intended to be base line inspection of the sleeves to which all subsequent inspections will be compared.

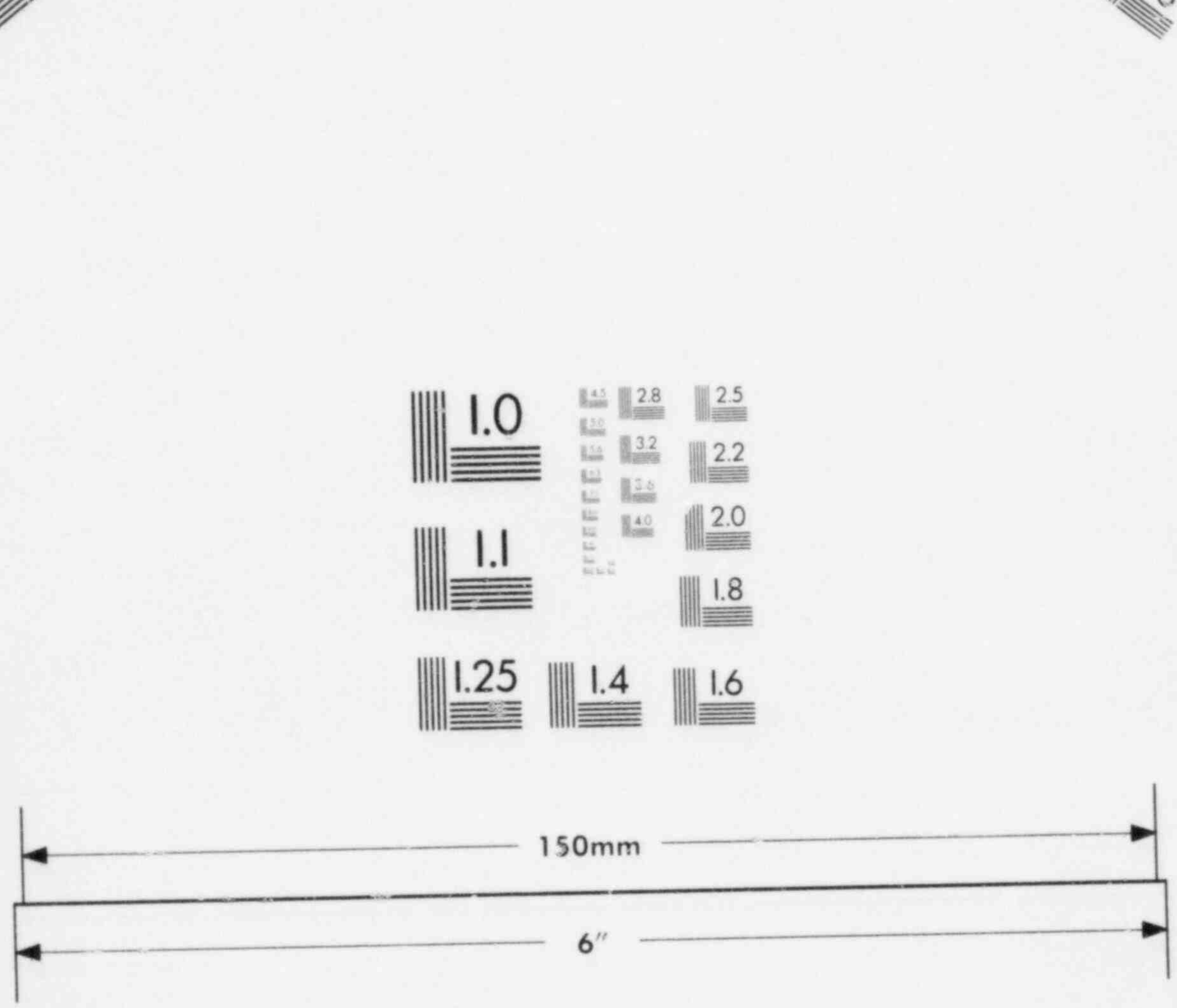
The inspection of the sleeved assembly has, in the past, involved the use of a conventional bobbin type probe operated with multi-frequency excitation. The sleeved assembly however, contains a number of geometric discontinuities which can make the evaluation of the tube condition more complex. Work has been performed to document the sensitivity of the bobbin coil inspection in these regions of geometric discontinuities. The results of this work on other sleeving applications was to identify the limits of sensitivity of the conventional coil inspection in this region. At the transitions in the sleeved assembly, degradation equivalent to 3 times the volume of the ASME calibration standard could be detected.

IMAGE EVALUATION
TEST TARGET (MT-3)

150mm

6"

IMAGE EVALUATION TEST TARGET (MT-3)



For the inspection of a sleeved assembly in the regions of geometric discontinuities, the probe consisting of cross-wound coils would be used along with the multi-frequency mixing technique. Such a system reduces the interference from the geometric discontinuities with 360-degree discontinuity and would provide higher visibility for tube degradation in these regions. It has been demonstrated in the laboratory that this technique can detect OD tube wall penetration at the transition regions when the volume of the metal involved is equivalent to that of the ASME calibration standard.

Figure 7.1-2 shows the eddy current signal from a 40 percent deep flat bottom hole on the OD of the tube at the transition region when using the cross-coil probe along with the multi-frequency mixing technique. As a reference, Figure 7.1-3 shows the signal of the ASME tube standard using the conventional bobbin probe with the multi-frequency system.

At the end of the sleeve, using a conventional bobbin probe, an inspection procedure involving comparison of the initial eddy current signatures with data from subsequent inspections will be used. The comparison of the eddy current signatures of this region has been found to be sensitive for detecting degradation of the tube wall. For example, it has been shown that a 40 percent uniform wall loss, 0.25 inch long centered at the end of the sleeve can be detected by this procedure. In addition, since the "cross-coil" probe is relatively insensitive to the discontinuities with 360° orientations, its use along with the multifrequency data processing technique would further improve the sensitivity near the sleeve end. Figure 7.1-4 shows the results of placing a 40 percent flat bottom hole in the tube at the sleeve end. Note that under these conditions, the signal from hole exceeds the residual sleeve and signal bv about a faster of 2.

Since no tube degradation has been observed where the sleeve joint will be placed, the present inspection procedures should be adequate for assessing the overall condition of the sleeve assembly after installation. Furthermore, it has been demonstrated in other sleeving applications that the standard inspection procedure will detect degradation in this region prior to it becoming a safety issue. In addition, at any region of the sleeve that is undistorted, the sensitivity of the inspection of the sleeve would be consistent with normal tubing inspection.

The probe size for the inspection of the sleeved region is smaller than the probe used for the inspection of the rest of the tube. If this probe is used for the inspection of the tubing above the sleeve, it may result in lower detectability for tube degradation. Thus, it may be necessary to inspect the tubing above the sleeve by inserting the standard size probe from the hot leg side in order to obtain acceptable sensitivity.

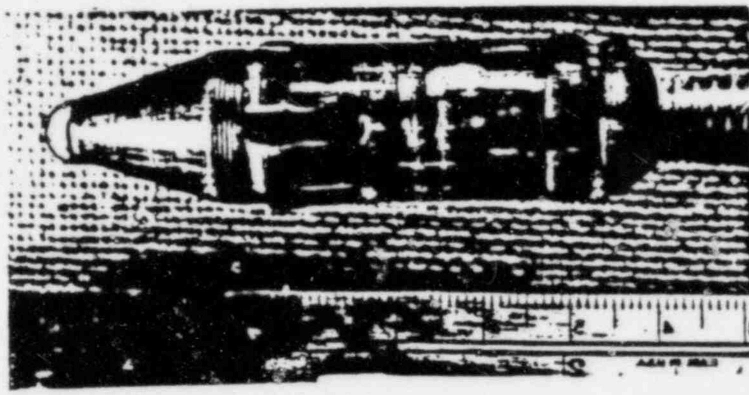
The axial location of the eddy current signals can be determined to within ± 0.5 inch by reproducing the data on the strip charts at higher speeds.

The development efforts aimed at the mechanical design of these probes to provide additional sensitivity are in progress at this time.

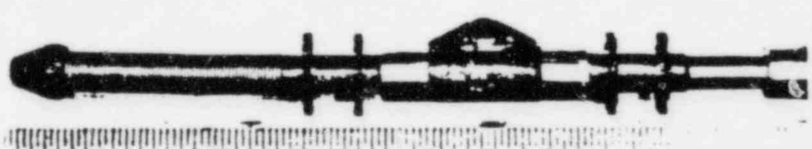
7.2 SUMMARY

Eddy current techniques have been modified to incorporate the most recent state-of-the-art technology in the inspection of the sleeve assembly. Eddy current techniques are a viable means of assessing the sleeve assembly for in-service inspection. Further research for advancing the state-of-the-art eddy current testing is continuing.

Conventional



a,c,e



Rotating Pancake

Figure 7.1-1 Eddy Current Probes

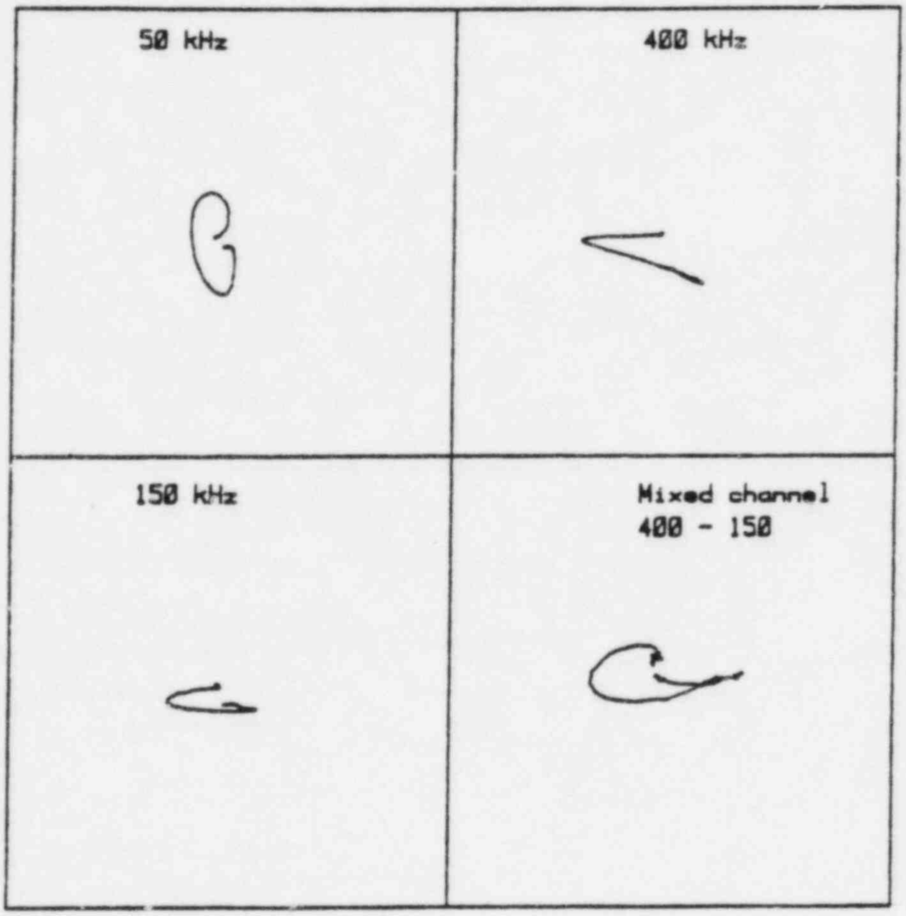


FIGURE 7.1-2

E. C. SIGNAL FROM A 40% ASTM STANDARD MACHINED ON THE TUBE O. D. IN THE EXPANSION TRANSITION REGION OF SLEEVE-TUBE ASSEMBLY (CROSS-WOUND COIL PROBE)

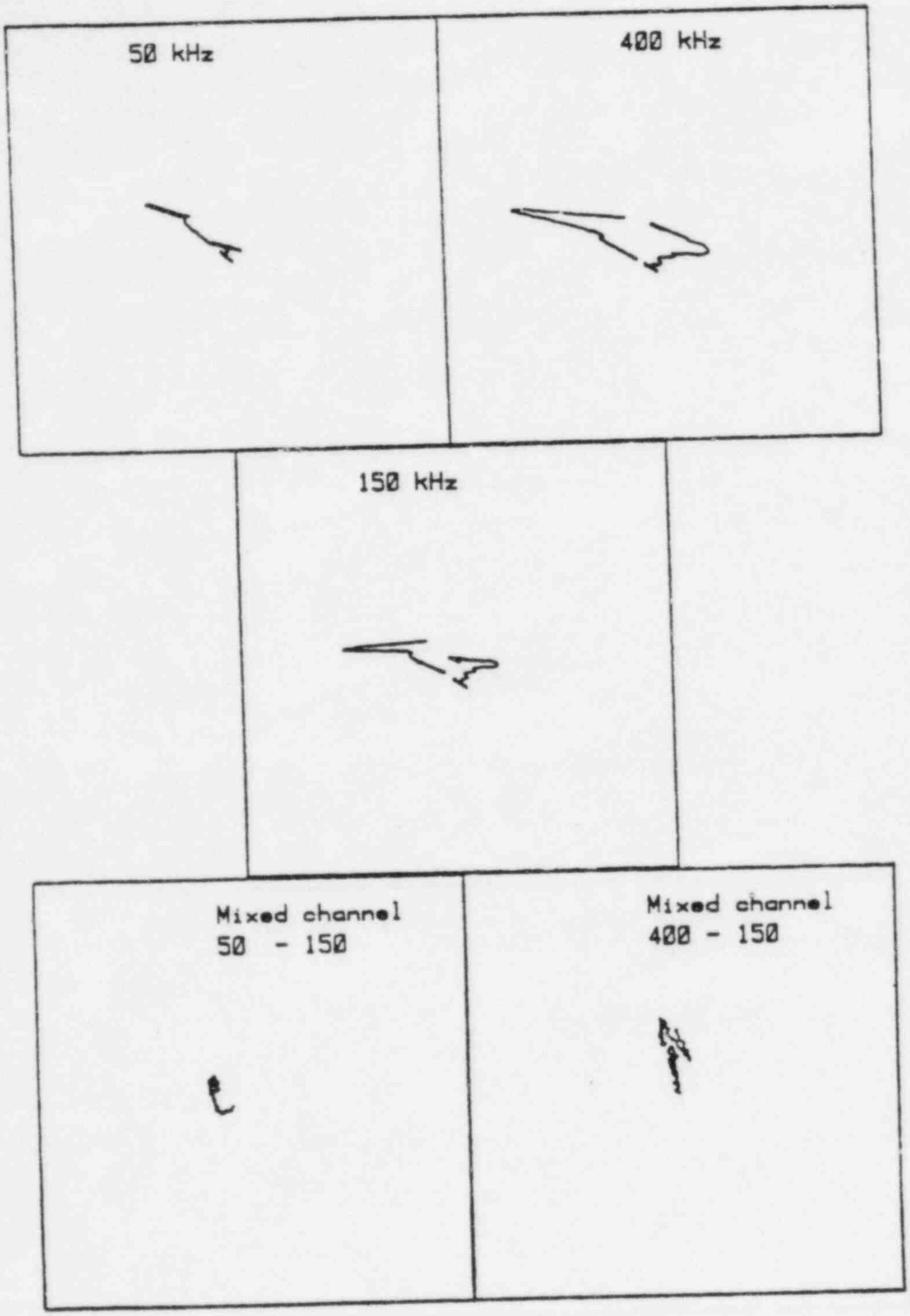


FIGURE 7.1-3

E. C. SIGNALS FROM THE EXPANSION TRANSITION REGION OF THE TUBE-SLEEVE ASSEMBLY (CROSS-WOUND COIL PROBE)

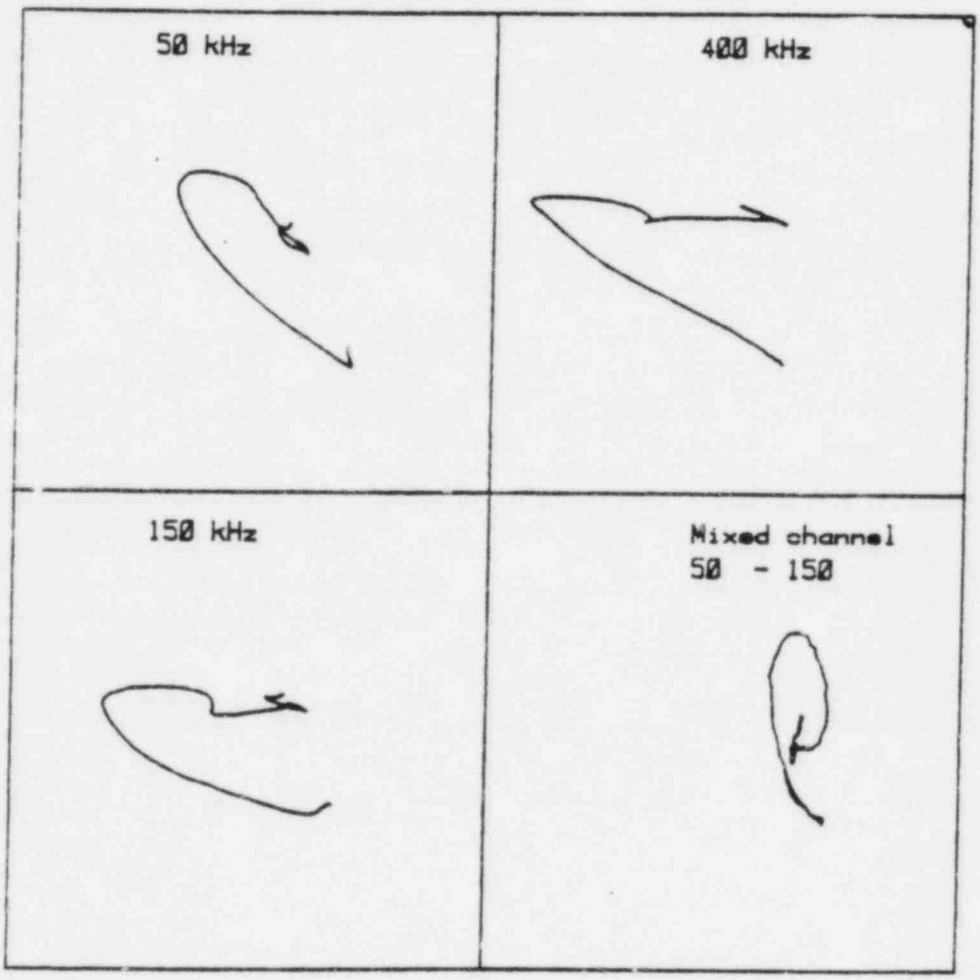


FIGURE 7.1-4a

E. C. SIGNALS FROM THE END OF SLEEVE REGION WITH A 40% ASME HOLE IN THE TUBE AT THE END OF THE SLEEVE.

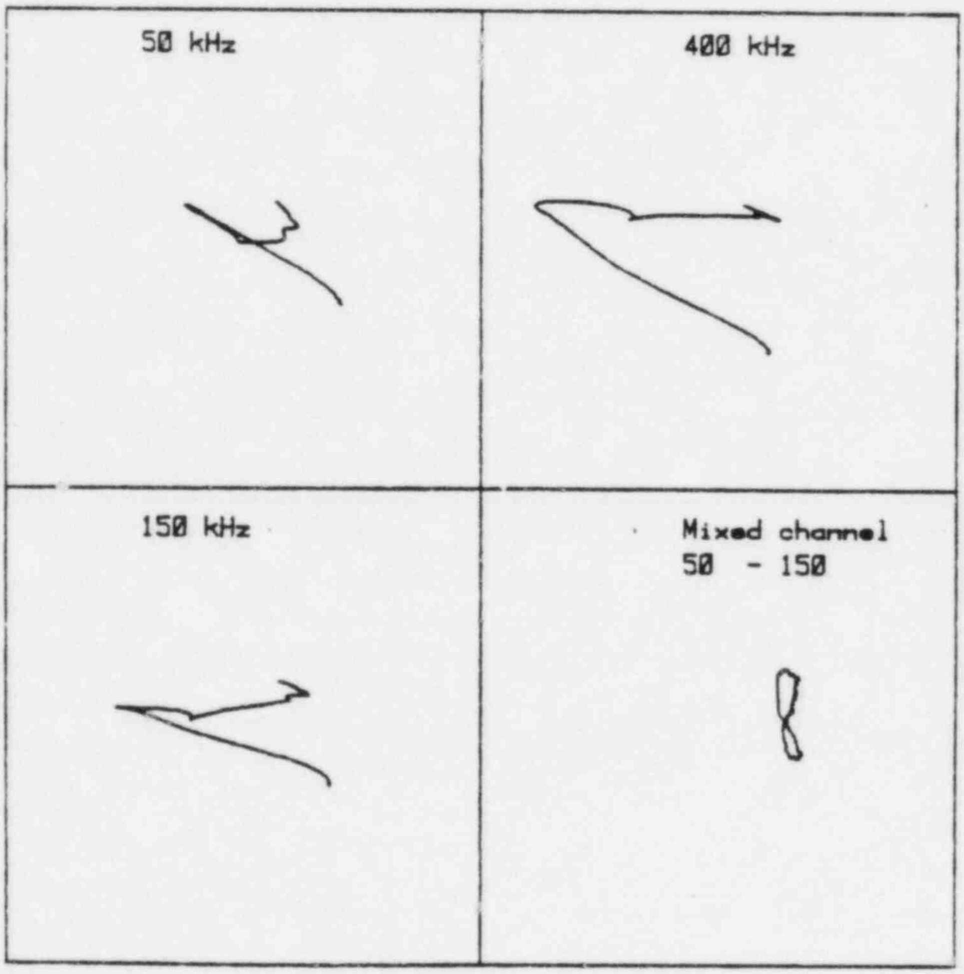


FIGURE 7.1-4b

E. C. SIGNALS FROM THE END OF SLEEVE REGION OF THE TUBE-SLEEVE ASSEMBLY (CROSS WOUND COIL PROBE)

8.0 ALARA CONSIDERATIONS

The repair of steam generators in operating nuclear plants requires the utilization of appropriate dose reduction techniques to keep radiation exposures as low as reasonably achievable (ALARA). Westinghouse Electric Corporation has committed significant resources so that the ALARA concepts and principles are integrated into the repair of steam generators in nuclear power plants. An extensive ongoing program to minimize radiation exposure to maintenance personnel consists of designing remote and semi-remote tooling, decontamination of steam generators, the use of shielding to minimize radiation exposure, and extensive training of personnel with strict qualifications. Only personnel who are fully qualified will be sent to the site.

The initial task in preparation for installing sleeves in the Millstone Unit 2 steam generators will be to decontaminate the channel heads. In this process the steam generator channel head surfaces and a segment of the tubes will be decontaminated, thus reducing the intensity of the source to which the channel head workers will be exposed. In addition to this, the nozzles will be shielded either by flooding the hot and cold legs or by providing temporary shielding. Additional shielding will be provided by a channel head wooden work platform covered by a layer of lead blankets. Shielding considerations are covered in Section 8.2.

The ALARA aspect of the tool design program is to develop special tooling to operate remotely in the high radiation fields. The controls for the equipment are located outside the channel head and, for the most part, outside containment. The tool design features were developed to minimize the number of channel head entries and to complete the sleeving project with total exposures kept to minimum, i.e., ALARA. Temporary shielding will be used wherever necessary to reduce the general area background at the work stations inside containment.

The control of personnel exposures can also be affected by the careful planning of maintenance procedures for the job. This form of administrative control can provide that the minimum number of personnel will be used to perform the various tasks. The use of TV and audio surveillance of all platform and

channel head operations, and the monitoring of personnel exposure for the purpose of identifying areas resulting in high exposures and to initiate corrective actions are additional methods of minimizing exposures. A combination of these techniques is expected to be used in the Millstone Unit 2 steam generator sleeving project.

8.1 TUBE CLEANING/DECONTAMINATION

The honing of tubes removes the oxide film from tube surfaces in preparation for installing sleeves and provides some decontamination in addition to channel head surface cleaning. The tube honing process contributes to the overall decontamination of the steam generator channel head surface. All tubes to be sleeved will be honed to a length of [ ]a,c,e

8.2 SHIELDING CONSIDERATIONS

An internal channel head platform is designed to provide a comfortable flat walking space and make reaching the tubesheet a simpler task. This reduces time in the channel head, thus reducing personnel exposure.

The platform is to be covered by a layer of lead blankets, designed to fit the annular shape of the platform for easy installation. The purpose of the lead blankets is twofold. First, it will shield some of the radiation coming out of the bottom fourth of the channel head bowl; secondly its cushioning effect provides better traction for workers inside the channel head. Furthermore, tool handling is facilitated in the event that a hanging tool falls. The impact on the platform will be lower, reducing the potential for breakage. This will result in less ineffective time due to equipment malfunctions and lower doses associated with maintenance.

Also, temporary shielding will be used wherever necessary to reduce the general area background radiation at appropriate work stations inside containment, such as adjacent to the non-regenerative heat exchanger.

The objective is to reduce the radiation environment to a minimum (ALARA) for work to be performed inside the channel head or at the manway. Additional

shielding both inside and outside the channel head will be considered and installed as needed.

8.3 RADIOACTIVE WASTE HANDLING

The solid radioactive waste generated in the process of sleeving consists primarily of spent hones, scrapped honing cables, and hone fluid filters. Liquid radioactive waste will be the effluent from the hone fluid filters (contaminated water.)

8.3.1 SOLID WASTE

The surface preparation of tubes for the installation of sleeves requires the oxide film to be removed by a wet honing process. A [

]a,c,e the film residue from the honed surfaces. The volume of solid radwaste is expected to consist of spent hones, flexible honing cables, and hone fluid filter assemblies. The activity in this waste is primarily Co-58 and Co-60.

8.3.2 LIQUID WASTE

The liquid waste will be generated from the wet honing step of the sleeving procedure. The honing fluid (water) will be filtered and then drained into the plant liquid radioactive waste system.

The quantity of water generated from honing operations is expected to be approximately [ ]a,c,e.

8.3.3 AIRBORNE RELEASES

The development of processes for sleeving operations at Indian Point 3 have indicated that the potential for airborne releases should be minimal. The major operations include tube honing and sleeve installations.

Due to the possibility of the presence of alpha contamination in the primary loop, "see through" enclosures will be installed to help contain any airborne radioactivity that may result from sleeving operations and related activities.

8.4 MAN-REM DOSE ESTIMATE

A preliminary approach to the prediction of the total dose for the Millstone 2 steam generator sleeving project is summarized in Figure 8.4-1. This figure plots the expected dose for the project as a function of the total number of sleeves to be installed for the expected radiation fields.

The assumptions used in estimating the man-rem dose are as follows:

1. Expected channel head (general area) radiation level: 6-8 R/hr after decontamination (expected decontamination factor: 2.5)

2. The exposure rate in the platform (general work area) is independent of the degree of decontamination achieved in the steam generator and, will remain constant at 150 mR/hr if no local shielding in the general area is used. Expected exposure rate at manway: 1.5 R/hr (after decontamination.)

3. Time estimates to perform the given steps of the sleeving operations are based on experience at Indian Point 3 (Westinghouse steam generator), qualification times during training and engineering judgement.

4. Sleeving to be done in the cold leg of each steam generator.

5. Use of the cartridge sleeve loader [

   ]a,b,c,e

6. Use of [
   ]a,c,e per steam generator.

7. Ten percent of the sleeves would be installed manually (hands-on.)

8. Radiation doses associated with delays in low radiation areas due to the presence of enclosures are negligible compared to the total dose for the project.

9. Twenty-five percent contingency is added to account for rework on all automatic operations; twenty percent contingency for rework is added on all manual operations.

10. Based on Indian Point 3 experience, 90 percent of the dose for the project is to be received by service technicians (platform and channel head workers). Doses computed on Appendices 8.1 and 8.2 (technician doses) are to be divided by 0.9 in order to get the predicted total dose for the project. This will account for all types of engineering support, health physics coverage, decontamination and other miscellaneous activities.

11. The same number of sleeves is to be installed in each steam generator.

The total estimated technician dose for the Millstone 2 sleeving project has the form $D_{TOTAL}^{TECH} = 174 + 0.170\ N_{TOTAL}$ (man-rems), where N_{TOTAL} is the total number of sleeves to be installed in the project. The total dose for the project (see assumption 10) has the form $D_{TOTAL} = 194 + 0.189\ N_{TOTAL}$ (man-rems). Appendices 8.1 and 8.2 show the derivation of these equations. It can be concluded from the given appendices that the use of automatic equipment during sleeving operations would reduce radiation exposures by approximately one order of magnitude, i.e., approximately the same dose would be obtained by installing 10 sleeves automatically (within the same tool position) or 1 sleeve manually.

The curve on Figure 8.4-1 does not extrapolate to the origin. The theoretical y-intercept (174 man-rems) represents the dose associated with installations/removals of the Coordinate Transport Machine and related end effectors.

Figure 8.4-1 plots the estimated technician and total doses for the project based on the given assumptions.

APPENDIX 8.1

The exposure times to perform all steps associated with the automatic sleeving process per steam generator are estimated as follows:

	EXPOSURE	TIME (man-minutes per SG)	
TASK	CHANNEL HEAD	MANWAY	GENERAL AREA
Channel head and Platform set up (cameras, lights, inner platform, lead blankets and template installation)	33	60	244
Installations/Removals of CTM, rails and cubes	112	120	736
Honing	20	27 + N*/22	400+ 4N/22
Sleeve insertion/ expansion	140+ 33N/230	$85+\frac{66N}{230}$	890+ 218 N/230
Lower, upper hard roll and tube mouth rework	60+ 3N/50	75+ 6N/50	790 + 30N/50
Eddy Current and baseline Eddy Current	40	70	480

*N = Number of sleeves to be installed per steam generator.

APPENDIX 8.1 (Continued)

TASK	EXPOSURE CHANNEL HEAD	TIME (man-minutes per SG) MANWAY	GENERAL AREA
Channel head and platform cleanup	21	35	203
Hands-on Rework	.04N	.08N	.16N
Miscellaneous (Camera adjustments, mechanical maintenance; QA and equipment malfunction delays)	.14N	.28N	1.52 N
TOTAL EXPOSURE TIME /SG (man-min)	426+ .383N	472+ .812N	3743+ 3.410N
+25 percent contingency for rework	532.5+ .479N	590+ 1.015N	4678.8 + 4.263N

Expected radiation levels (in mR/min):

CHANNEL HEAD	MANWAY	GENERAL AREA
114 (6.8 R/hr)	25 (1.5 R/hr)	2.5 (150 mR/hr)

By multiplying the estimated exposure time in the three different radiation areas of concern by the respective expected radiation levels, the total estimated dose per steam generator to be received in each location can be calculated. When adding these three doses and multiplying by 2 (two steam generators), the total technician dose (automatic operations) takes the form of:

TOTAL TECHNICIAN DOSE (man-rems)	TOTAL DOSE FOR THE PROJECT * (man-rems)
$174 + 0.091\ N_{tot}$	$194 + 0.101\ N_{tot}$

$$\text{*Total dose for the project} = \frac{\text{total technician dose}}{0.90 \text{ (from assumption 10)}}$$

N_{tot}=total number of sleeves to be installed automatically in the project = 2N

APPENDIX 8.2

DERIVATION OF THE ESTIMATED HANDS-ON DOSE EQUATION FOR MILLSTONE UNIT 2 SLEEVING PROJECT

A. Definitions

D = doses in milli man-rems

X = channel head exposure rate in mR/min

N = number of processes of that type

B. Estimated Doses by Process (include contingency for rework)

1. Honing: $D_{HON} = 5.17(X)(N_H)$

2. Fiberscoping: $D_{Fib} = 0.54(X)(N_F)$ (remember fiberscoping is a a y-10 operation)

3. Insertion/expansion: $D_{I/E} = 2.71(X)(N_I)$

4. Lower Hard Roll and tube mouth rework:

   $D_{LHR} = D_{TMR} = 1.03(X)(N_L)$

5. Upper Hard Roll: $D_{UHR} = 2.17(X)(N_U)$

C. Overall

Total dose $D = (\dot{X})(5.17NH + \frac{0.54NF}{10} + 1.03N_{TM} + 2.71N_I + 1.03N_L + 2.17N_U$

assuming $N_H = 10N_F = N_{TM} = N_I = N_L = N_U = N_T$

where N_T = total hands-on sleeves

$D = 12.16\ (X)(N_T)$

This dose applies for tubes to be sleeved falling completely outside the automatic sleeving boundary. Where plug/camlock tooling interference occurs inside the automatic sleeving boundary, only items B.3 through B.5 are performed hands-on such that the above approximation becomes:

$$D' = 6.94(X)N_T'$$

The majority of the hands-on sleeving would fall into this category. For X = 114 mR/min (6.8 R/hr),

$$D' = 0.79N_T' \text{ (technician dose, man-rems)}$$

Using assumption (10): $D' = 0.88\ N_T'$ = total dose for the project (manual operations)

Combining results on Appendices 8.1 and 8.2:

Automatic Operations:

$$D_{tot}^{TECH} = 174 + 0.091\ N_{tot};\ D_{tot} = 194 + 0.101\ N_{tot} \text{ (man-rems)}$$

Manual Operations:

$$D_T^{TECH} = 0.79\ N_T';\ D_T = 0.88\ N_T' \text{ (man-rems)}$$

From assumption (7): $N_{tot} = 10\ N_T'$; therefore,

$$D_{TOTAL} = 194 + 0.189\ N_{TOTAL} \text{ (man-rems)}$$

N_{TOTAL} is the total number of sleeves to be installed in the project $= N_{tot} + N_T'$

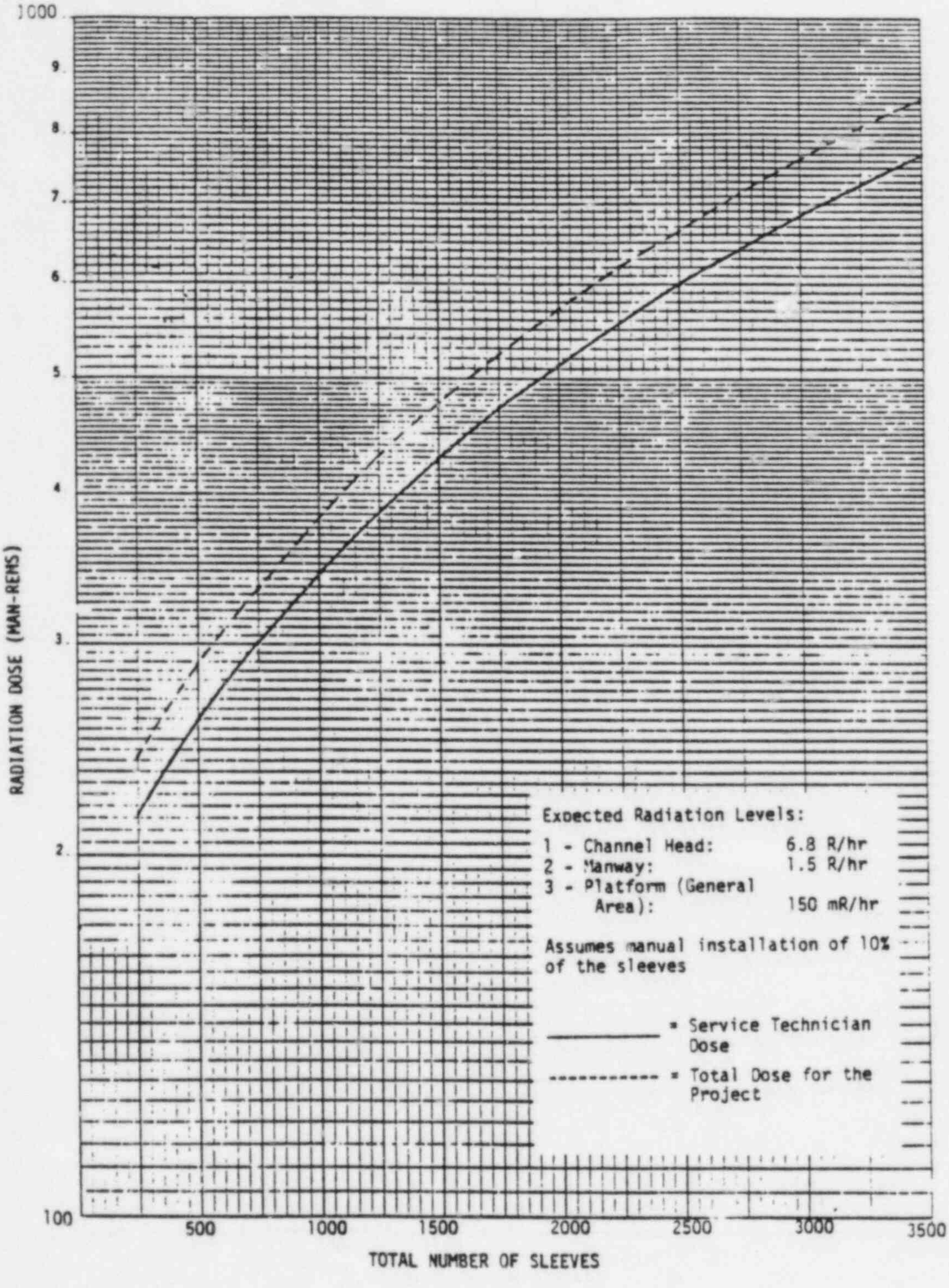


Figure 8.4-1: Preliminary Man-Rem Estimate for the Millstone 2 Sleeving Project

9.0 INSERVICE INSPECTION PLAN FOR SLEEVED TUBES

In addressing current NRC requirements, the need exists to perform periodic inspections of the supplemented pressure boundary. This new pressure boundary consists of a sleeve with a joint at the primary face of the tubesheet and a joint at the top end of the sleeve.

The inservice inspection program will consist of the following. The sleeves will be eddy current inspected to obtain a base line signature. Periodic inspections will be performed in accordance with the Millstone 2 Technical Specifications to monitor sleeve wall conditions. This inspection will be performed with standard multi-frequency eddy current equipment. The plugging criterion for the sleeves is established on the same basis developed for the original tubes.

As part of the inspection of the sleeved tubes, there will be a series of pressure tests. These tests are intended to test the integrity of the mechanical joint against leakage at both primary and secondary pressure loadings. The tests will be conducted at the conclusion of the sleeving operation and will be performed by Northeast Utilities Service Company in accordance with applicable requirements of the ASME code. Periodic pressure testing of the sleeved tubes will also be performed in accordance with the Millstone 2 Technical Specifications.

APPENDIX A

SCE TEST PROGRAM

RESULTS

TASK M5

SLEEVE-TO-TUBE ROLLED JOINT LEAK-TIGHT TEST

OBJECTIVE

Demonstrate that the rolled joint can perform its intended structural function and remain leaktight under normal and postulated accident conditions.

[ ] a,b,c

FACILITY

Ambient pressure furnace, axial fatigue testing machine and hydrostatic test pump with pressure gauge (schematic shown in Fig. 6.1.10 followed by test set-up Fig. 6.1.11).

TEST AND CRITERIA

Four thermal cycles up to 650°F and 8500 axial loading cycles of ± 2000 psi. Joint must be leaktight for 10 minutes under hydrostatic test at 3728 psi.

STAUTS

Qualification test completed on five specimens-no leak.

TABLE 4.1

HEJ TEST DATA SUMMARY

REFERENCE DATA

MOCKUP NUMBER	DESCRIPTION a,c,e	LEAK RATE (DROPS/MIN) 1500 PSI	2400 PSI	TEMP.	YIELD LOAD (LBS)	OTHER
S-4		Before Pull			3200	
		0.0	0.0	Room		
		After Pull				
		1.0	0.5	Room		
S-21		Before Pull			2750	
		0.0	0.0	Room		
		After Pull				
		1.7	1.9	Room		
S-22		Before Pull			2175	
		0.0	0.0	Room		
		After Pull				
		0.4	2.6	Room		
S-23		Before Cycle				Cycled in Water
		0.0	0.0	Room		1500 Cycle -
		After Cycle			More Than	
		0.3	---	600°F	-2290	
		After Push				
		0.0	0.0	Room		
S-28		Before Cycle				Cycled in Water
		0.0	0.0	Room		1500 Cycle -
		After Cycle			More Than	
		0.9	---	600°F	-2290	
		After Push				
		0.0	0.0	Room		

TABLE 4.1 (Continued)

HEJ TEST DATA SUMMARY

REFERENCE DATA

MOCKUP NUMBER	DESCRIPTION	LEAK RATE (DROPS/MIN) 1500 PSI	2400 PSI	TEMP.	YIELD LOAD (LBS)	OTHER
S-29		Before Cycle				
		0.0	0.0	Room		
		After Cycle				
		1.3*	-	600°F	More Than 1780	
		After Push				
		0.0	0.4	Room		
S-31		Before Cycle				
		0.0	0.0	Room		
		After Cycle				
		1.7*	-	600°F	More Than 1675	
		After Push				
		0.0	0.0	Room		
S-32		Before Cycle				
		0.0	0.0	Room		
		After Cycle				
		0.1*	-	600°F	More Than 1900	
		After Push				
		0.0	0.0	Room		

*1600 psi.

TABLE 4.1 (Continued)

HEJ TEST DATA SUMMARY

REFERENCE DATA

MOCKUP NUMBER	DESCRIPTION	LEAK RATE (DROPS/MIN) 1500 PSI	2400 PSI	TEMP.	YIELD LOAD (LBS)	OTHER
S-33		Before Cycle				Cycled in Steam
		0.0	0.0	Room		3000 Cycle -
		After Cycle			>1,940	
		1.3	-	600°F	(Push)	
A-1		Before Push				
		0.0	0.0	Room	>1,700	Max. Mandrel
		After Push			Push	Movement.
		0.0	0.0	Room		
A-6		Before Push				
		0.0	0.0	Room	>2,300	Max. Mandrel
		After Push			Push	Movement.
		0.0	0.0	Room		
BLT-18		Before Pull				
		0.0	0.0	Room	2,430	Max. Mandrel
		After Pull				Movement.
		0.0	1.0	Room		
A-2		Before Cycle				
		0.0	0.0	Room	3,100	
		After Cycle				
		0.0*	-	600°F		
		After Push				
		0.0	1.4	Room		

*1600 psi.

TABLE 4.1 (Continued)

HEJ TEST DATA SUMMARY

REFERENCE DATA

MOCKUP NUMBER	DESCRIPTION	LEAK RATE (DROPS/MIN) 1500 PSI	2400 PSI	TEMP.	YIELD LOAD (LBS)	OTHER
A-4		Before Cycle				
		0.0	0.0	Room	2,290	
		After Cycle				
		0.1*	-	600°F		
		After Push				
		0.5	1.4	Room		
A-5		Before Cycle				
		0.0	0.0	Room	2,930	
		After Cycle				
		0.0*	-	600°F		
		After Push				
		1.1	2.1	Room		
A-7		Before Cycle				
		0.0	0.0	Room	3,160	
		After Cycle				
		0.0*	-	600°F		
		After Push				
		0.0	0.3	Room		
A-8		Before Cycle				
		0.0	0.0	Room	2,930	
		After Cycle				
		1.6*	-	600°F		
		After Push				
		0.4	1.4	Room		

*1600 psi.

TABLE 4.1 (Continued)

HEJ TEST DATA SUMMARY

REFERENCE DATA

MOCKUP NUMBER	DESCRIPTION	LEAK RATE (DROPS/MIN) 1500 PSI	2400 PSI	TEMP.	YIELD LOAD (LBS)	OTHER
A-9		Before Cycle				
		0.0	0.0	Room	3,060	
		After Cycle				
		0.0*	-	600°F		
		After Push				
		0.1	1.1	Room		
FF-3		0*	0	Room		axial Load Supported by Braze
		0*	0	600°F		

*1600 psi.

a,c,e

Figure 6.1.10

Test Facility for Pressure Cycling Test
for Simulation of Plant Loading and Unloading Transient

a,c,e

Figure 6.1.11 Single Tube Model Boiler Test Setup

Appendix B

SPECIFICATION SP-ME-394

PA 82-130

Project

Specification For:

Millstone Unit 2

Steam Generator Tube Repair Program

THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION OF THE WESTINGHOUSE ELECTRIC CORPORATION (NUCLEAR SERVICE DIVISION) AND NORTHEAST UTILITIES AND IS TO BE RETURNED UPON REQUEST. ITS CONTENTS MAY NOT BE DISCLOSED TO OTHERS OR USED FOR OTHER THAN THE EXPRESSED PURPOSE FOR WHICH LOANED WITHOUT THE WRITTEN CONSENT OF WESTINGHOUSE (NUCLEAR SERVICE DIVISION / NORTHEAST UTILITIES SERVICE COMPANY.

NORTHEAST UTILITIES SERVICE COMPANY

FOR

MILLSTONE UNIT 2

QA CATEGORY I

Rev. #/DATE	DESCRIPTION	ORIGINATED BY	REVIEWED BY	QA APPROVAL	APPROVED BY
Rev. 1/3-18-83	Initial Issue	R.M. Hunechka 22 March 83	[illegible] 3/24/83	J. Borysewicz 3/24/83	M. Kupinski 3-23-83
Rev. 2/4-5-83		R.M. Hunechka 14 Apr 1983	[illegible] 4/7/83	J. Borysewicz 4/10/83	[illegible]
Rev. 3/8-2-83	Correction to Figure 4	R.M. Hunechka 2 Aug 1983	[illegible] 8/4/83	P Newman [illegible]	M. Kupinski 8-3-83

DESIGN REQUIREMENTS

1.0 The tube sleeve and tube/sleeve assembly repair are to be capable of carrying the calculated steady-state and cyclic loads during postulated accident and normal operating conditions to ASME III, Subsection NB3200.

2.0 The installed sleeves and sleeved tubes are to be accessible for in-service inspection over the entire length of the sleeved tube region.

3.0 The sleeving process is not to impair the pressure retaining capability of the unsleeved portions of the tube for the remaining design life of the steam generators.

4.0 The sleeve material selection is to provide resistance to stress corrosion cracking on both the primary and secondary sides and pitting from the secondary side.

4.1 The sleeve material should be compatible to the original steam generator design document water chemistry as contained in Table I.

4.2 The sleeve material shall offer pitting resistance in secondary side environment within sludge of chemical composition as contained in Table II.

5.0 The sleeve is to be designed to minimize effects upon primary flow resistance.

6.0 The repair is to limit the primary-to-secondary side leak rate for each sleeve such that the total aggregate leakage of the steam generators shall be less than leakage limits as specified in the Millstone Unit No. 2 Safety Technical Specifications.

7.0 The installed sleeves are to be structurally adequate.

8.0 Design basis shall be in accordance with ANSI N18.2a, Class 1 Safety Classification.

9.0 Design Analyses

9.1 The tube sleeve and tube/sleeve assembly shall be designed to meet the applicable guidelines of ASME Boiler and Pressure Vessel Code, Section III, NB-3200.

9.2 The principal design parameters for the steam generator are listed in Table III and Figure 1.

9.3 The following design cyclic transients, which include conservative estimates of the operational requirements for the steam generators shall be used in fatigue analyses required by the applicable ASME Code. The applicable operating condition category as designated by ASME Section III is indicated in each case.

9.3.1 Five hundred heat-up and cool-down cycles during the steam generators' 40-year design life objective at a heating and cooling rate of 100°F/hour between 70°F and 532°F. See Figure 2. Category: Normal Condition.

9.3.2 Fifteen thousand power change cycles over the range of 15 percent to 100 percent of full load with a ramp load change of five percent of full load per minute increasing and decreasing. See Figure 3. Category: Normal Condition.

9.3.3 Two thousand cycles of ten percent of full load step power changes, increasing from an initial level of 15 and 90 percent of full power and decreasing from an initial power level between 15 and 100 percent of full power. See Figure 4. Category: Normal Condition.

9.3.4 10^6 cycles of normal variations of ± 100 psi and ± 6°F on primary side and ± 40 psi on secondary side at operating temperature and pressure. Category: Normal Condition.

9.3.5 Four thousand cycles of transient pressure differentials of 85 psi across the primary head divider plate due to starting and stopping the primary coolant pumps. Category: Normal Condition.

9.3.6 Fifteen thousand cycles of adding 600 gpm per steam generator of 70°F feedwater with the plant in hot standby condition (no load, normal water level, 532°F). The duration of this water injection is approximately 21.6 minutes, which is the time required to raise the water level from minimum control level to the upper control level. Category: Normal Condition.

9.3.7 Four hundred reactor trips from 100 percent power. See Figure 5. Category: Upset Condition.

9.3.8 Forty cycles of total loss of reactor coolant flow when at 100 percent power. See Figure 6. Category: Upset Condition.

9.3.9 Forty cycles of loss of turbine load from 100 percent power with a delayed, reactor trip. See Figure 7. Category: Upset Condition.

9.3.10 Five cycles of complete loss of secondary system pressure. The tube sleeve and tube/sleeve assembly should not be structurally damaged under loss of secondary pressure which may produce a fluid velocity in the secondary side four (4) times design velocity. See Figure 8. Category: Emergency Condition.

9.3.11 Eight cycles of adding a maximum of 650 gpm of 70°F feedwater with the steam generator side dry and at 620°F. Assume that the secondary side pressure is atmospheric. Category: Emergency Condition.

9.3.12 Ten cycles of hydrostatic testing of the secondary side at 1250 psig, the primary side is at atmospheric pressure. The secondary side temperature will be 100°F. Category: Test Condition.

9.3.13 Ten cycles of primary side hydrostatic testing of the steam generator at 3125 psia. The secondary side pressure shall be at atmospheric pressure. The primary side will be at 100 to 400°F. Primary side pressurization and depressurization shall be scheduled in accordance with Figure 9. Category: Test Condition.

9.3.14 Two hundred cycles of leak testing the primary side system from 2250 to 2500 psia, at temperatures between 100°F and 400°F, as dictated by components nil ductility transition temperature. At the same time, the secondary side will be pressurized so that the pressure differential, primary to secondary does not exceed 2250 psi. Maximum primary side heat-up and cool-down rate shall be 100°F/hour. See Figure 10. Category: Test Condition to be evaluated as Upset Condition.

9.3.15 Two hundred cycles of leak testing of the secondary side from 820 to 1000 psia, at temperatures between 100-200°F. At the same time, the primary side will be pressurized so that the pressure differential secondary to primary does not exceed 820 psi. Category: Test Condition to be evaluate as Upset Condition.

9.3.16 Pressure loading summary for the transient conditions considered is contained in Table IV.

9.4 Thermal-hydraulic performance effects of sleeved tubes shall be analyzed. The primary side hydraulic pressure drop and associated flow resistance of a sleeved tube shall be calculated. The effect of sleeves upon steam generator plugging margin shall be determined.

9.5 Millstone Unit No. 2 has been licensed for loss-of-coolant accidents (LOCA) and main steam line break (MSLB). The sleeve and sleeved tube assembly shall be analyzed for these postulated accident conditions. Postulated accident conditions pressure loadings are contained in Table V.

9.6 Sludge height thermal effects shall be evaluated.

9.7 The minimum required sleeve wall thickness to sustain normal and accident load conditions shall be calculated in accordance with guidelines of Regulatory Guide 1.121.

9.8 For design analyses purposes, sketches of the Millstone Unit No. 2 Steam Generator tubesheet/channel head and eggcrate locations are provided in Figures 11 and 12, respectively.

9.9 For design analyses purposes, steam generator primary side tube flow velocities are contained in Table VI.

9.10 For design analyses purposes, secondary side temperatures are to be considered saturation temperatures unless noted otherwise. Transients and corresponding secondary temperatures are contained in Table VII.

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TABLE I

WATER CHEMISTRY REQUIREMENTS

Primary Coolant Water Chemistry

Specific Resistivity, prior to additives	∞ to 0.5 megohm-cm
Total Solids, other than additives	0 to 2.0 ppm
pH (573°F) calc.	5.3 to 8.8
pH (77°F)	4.5 to 10.6
Dissolved Hydrogen	0 to 100cc (STP) H_2/Kg H_2O
Dissolved Nitrogen	0 to 100cc (STP) N_2/Kg H_2O
Dissolved Oxygen	
Plant Cold (less than 150°F)	Not Specified*
Plant Hot (above 150°F)	0 to 0.1 ppm O_2*
Halides	
Chloride	0 to 0.15 ppm Cl
Fluoride	0 to 0.1 ppm F
Boric Acid	0 to 15,000 ppm H_3BO_3
Additives for pH Adjustment	
Ammonium Hydroxide (NH_4OH)	0 to 50 ppm NH_3**
Lithium Hydroxide (LI^7OH)	0 to 2.5 ppm Li^7
Hydrazine (N_2H_4)	0 to 200 ppm N_2H_4**

* Hydrazine is added to recirculating coolant during heat-up if required to remove excess O_2. The system cannot exceed 150°F until the O_2 design limit or a hydrazine residual is established.

**50 to 200 ppm N_2H_4 used for cold standby operation before core loading. On heatup NH_3 produced by thermal decomposition of N_2H_4 limited to 100 ppm NH_3.

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TABLE I (Cont'd)

Feedwater Chemistry

Total Solids	
Normal Operation	0 to 0.5 ppm
Abnormal, 4-hour limit	0.5 to 2.0 ppm
Immediate orderly shutdown	greater than 2.0 ppm
Total Chlorides	0 to 0.2 ppm Cl
Total Dissolved Oxygen	0 to 0.01 ppm O_2
Total Silica	0 to 0.02 ppm Si
pH	8.5 to 10.0
Additives	
Hydrazine	1.5 times oxygen Concentration
Morpholine	As required for pH control
Cyclohexylamine	As required for pH control
Ammonia	As required for pH control

Recirculating Water Chemistry

Total Solids	0 to 1,000 ppm
Suspended Solids	0 to 60 ppm
Total Chlorides	0 to 75 ppm Cl
Total Dissolved Oxygen	0.0 ppm O_2
Total Silica	0 to 20 ppm Si
pH (77°F)	9.0 to 10.4
Total Free Hydroxide	0
Additives	
Phosphate	15-25 ppm PO_4
Sulphite	5-10 ppm SO_3

TABLE II

X-RAY FLUORESCENCE
SLUDGE SAMPLES

	Tubesheet Sludge Percent	
Elements	Tube 68/58	109/63
Li	< .05	< .05
C	.5	.3
Na	.16	.16
Mg	.06	.01
Al	.35	.73
Si	.29	1.8
P	.02	.11
S	.11	.82
Cl	< .02	< .02
K	.16	.23
Ca	.24	.5
Ti	.17	.2
Cr	.12	.15
Mn	.02	.02
Fe	29.8	30.2
Ni	1.9	1.5
Cu	46.3	41.5
Zn	5.1	4.5
Pb	.27	.27

NOTES: (1) Li, Na, Mg determined by emission spectroscopy. C determined by gas chromatography.
(2) Values preceded by "<" are the minimum detectable percentages.

TABLE III

STEAM GENERATOR PARAMETERS

Number	2
Type	Vertical U-Tube
Number of Tubes (Design/Actual)	8485/8519
Tube Outside Diameter, in.	0.750
Heat Transfer Rate, ea. Btu/hr.	4.385×10^9
Nozzles and Manways	
Primary Inlet Nozzle (1 ea.), ID, in.	42
Primary Outlet Nozzle (2 ea.), ID, in.	30
Steam Nozzle (1 ea.), ID, in.	34
Feedwater Nozzle (1 ea.), nominal, in.	18
Instrument Taps (12 ea.), nominal, in.	1
Primary Manways (2 ea.), ID, in.	16
Secondary Manways (2 ea.), ID, in.	16
Secondary Handhole (2 ea.), ID, in.	6
Bottom Blowdown (1 ea.), nominal, in.	2
Surface Blowdown (1 ea.), nominal, inc.	1
Primary Side Design	
Design Pressure, psig	2485
Design Temperature, F	650
Design Thermal Power (NSSS), Mwt	2700
Coolant Flow (ea.), lb/hr.	61×10^6
Normal Operating Pressure, psia	2250
Coolant Volume, ea., ft^3	1646
Secondary Side Design	
Design Pressure, psig	1000
Design Temperature, F	550
Normal Operating Steam Pressure, Full Load, psig	870
Normal Operating Steam Temperature, Full Load, F	520.3
Blowdown Flow, Design, Maximum, ea., lb/hr.	112,000
Steam Flow, ea., lb/hr.	5.603×10^6
Steam Moisture Content, Maximum, percent	0.20
Feedwater Temperature, F	435
Number of Steam Separators, ea. S.G.	166
Number of Steam Dryers, ea. S.G.	126
Dimensions	
Overall Height, Including Support Skirt, in.	749
Upper Shell Outside Diameter, in.	239-3/4
Lower Shell Outside Diameter, in.	165
Weights	
Dry, lb.	1,009,089
Flooded, lb.	1,602,988
Operating, lb.	1,230,348

TABLE IV

PRESSURE LOADING SUMMARY

		P Pri. Max. PSIA	P Pri. Min. PSIA	P Sec. Max. PSIA	P Sec. Min. PSIA
1.	Design Condition	2,500	15	1,015	15
2.	Plant Heat Up	2,250	15	900	15
3.	Plant Cool Down	2,250	15	900	15
4.	Plant Loading	2,320	2,250	868	815
5.	Plant Unloading	2,320	2,180	868	815
6.	10-Step Load Increase	2,340	2,250	820	815
7.	10-Step Load Decrease	2,250	2,180	820	815
8.	Reactor Trip	2,260	1,760	900	815
9.	Cold Feedwater Following Hot Standby	2,250	2,250	900	900
10.	Steady State Fluctuations	2,350	2,150	855	775
11.	Loss of Feedwater Flow	-	2,250	15	15
12.	Loss of Flow	2,280	1,880	900	815
13.	Loss of Load	2,420	1,720	900	815
14.	Loss of Secondary Pressure	2,250	160	900	15
15.	Subsequent Primary Side Pressure Tests	3,125	15	-	-
16.	Subsequent Secondary Side Pressure Tests	-	-	1,265	15
17.	Primary to Secondary Leak Tests	2,500	15	250	15
18.	Secondary to Primary Leak Tests	180	15	1,000	15
19.	Pump Starting and Stopping	2,235	2,165	815	815

TABLE V

DESIGN, FAULTED AND TEST CONDITIONS

CONDITIONS	REFERENCE	Sleeve Pressure Loading (psig) PRIMARY	SECONDARY
Design	Section III design margin	2,485	1,000
Faulted (MSLB)		2,285	0
Faulted (LOCA)		0	1,035

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TABLE VI

Information for primary side tube flow velocities are as follows:

1. Average Flow Velocity - Tube Inlet at 596°F = 25.5 ft/sec

2. Averate Flow Velocity - Tube Outlet at 548°F = 23.6 ft/sec

3. Shortest Unplug Tube Length = 528-11/16"

4. Average Unplug tube Length = 688-1/2"

5. Longest Unplug Tube Length = 899"

Assumed core conditions T_{IN} = 548°F, T_{OUT} = 596°F, flow rate at RCP and 548°F = 383,900 gpm.

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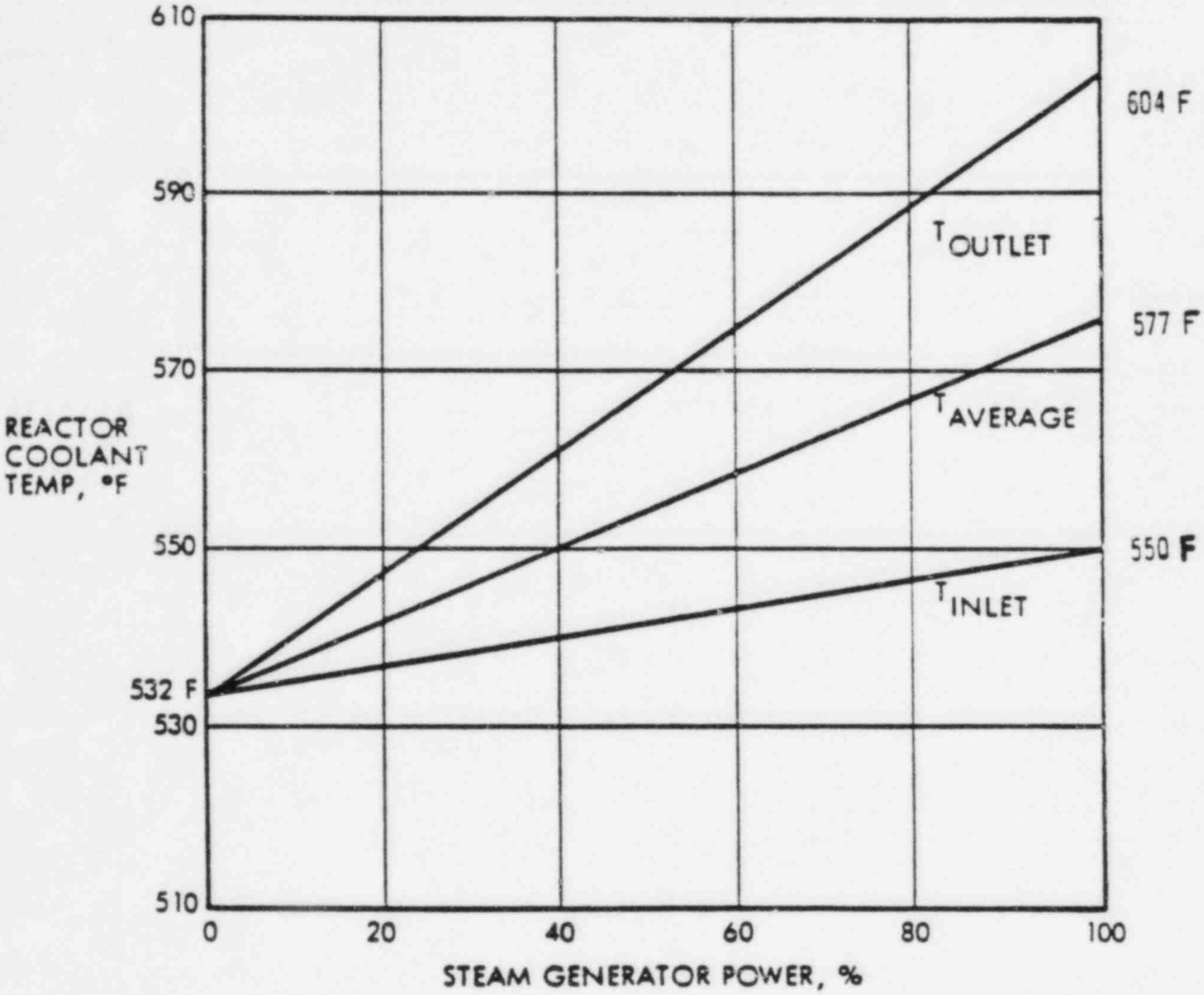
TABLE VII

TRANSIENTS AND ASSOCIATED SECONDARY SIDE TEMPERATURES

TRANSIENT	TIME	Tm
PLANT HEATUP	INITIAL	70
	4.5 HR.	508
	4.62 HR	520
	5.0 HR	531
0% LOAD STEADY STATE		532
PLANT COOLDOWN	4.5 HR	94
	4.62 HR	82
	5.0 HR	71
	FINAL	70
PLANT LOADING	15% S.S.	528
	~	528
100% LOAD STEADY STATE		520
PLANT UNLOADING	~	520
	15% S.S.	528
LOAD INCREASE	90% S.S.	522
	~	522
100% LOAD STEADY STATE		520
LOAD DECREASE	~	520
	90% S.S.	522
REACTOR TRIP	100% S.S.	520
	~	520
	0% S.S.	532
NORMAL PLANT VARIATIONS	100% S.S.	520
	+40 PSI	520
	FINAL	520
	100% S.S.	520
	-40 PSI	520
	FINAL	520

TRANSIENT	TIME	Tm
LOSS OF FLOW	100% S.S.	520
	~	520
	0% S.S.	532
LOSS OF LOAD	100% S.S.	520
	~	520
	0% S.S.	532
COLD FEED FOLLOWING HOT STANDBY	0% S.S.	532
	12 MIN.	532
	14 MIN.	532
	21.6 MIN.	532
	FINAL	532



610
590
570
550
532 F
530
510
REACTOR
COOLANT
TEMP, °F
604 F
T_{OUTLET}
577 F
$T_{AVERAGE}$
550 F
T_{INLET}
0
20
40
60
80
100
STEAM GENERATOR POWER, %

FIGURE 1

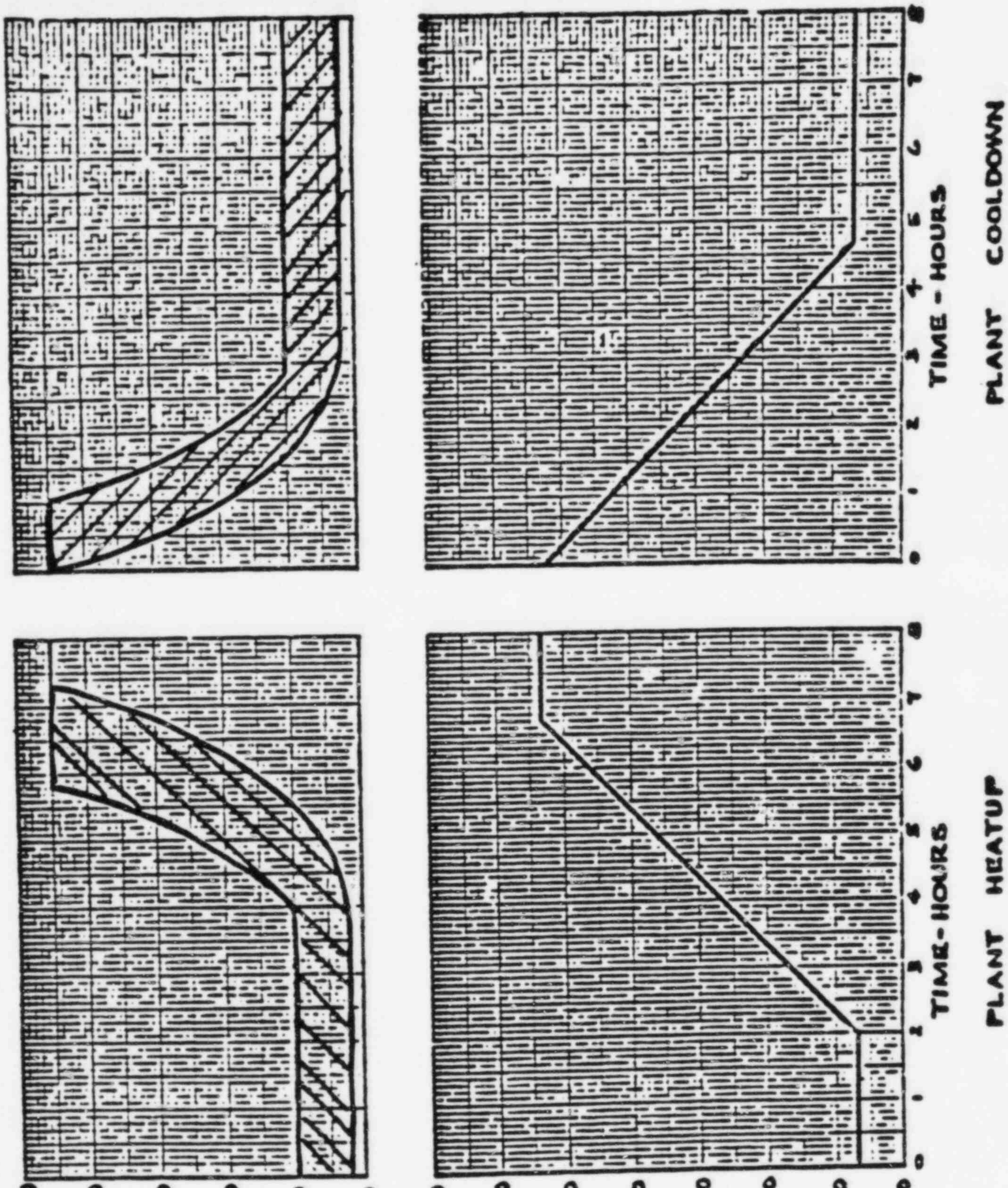
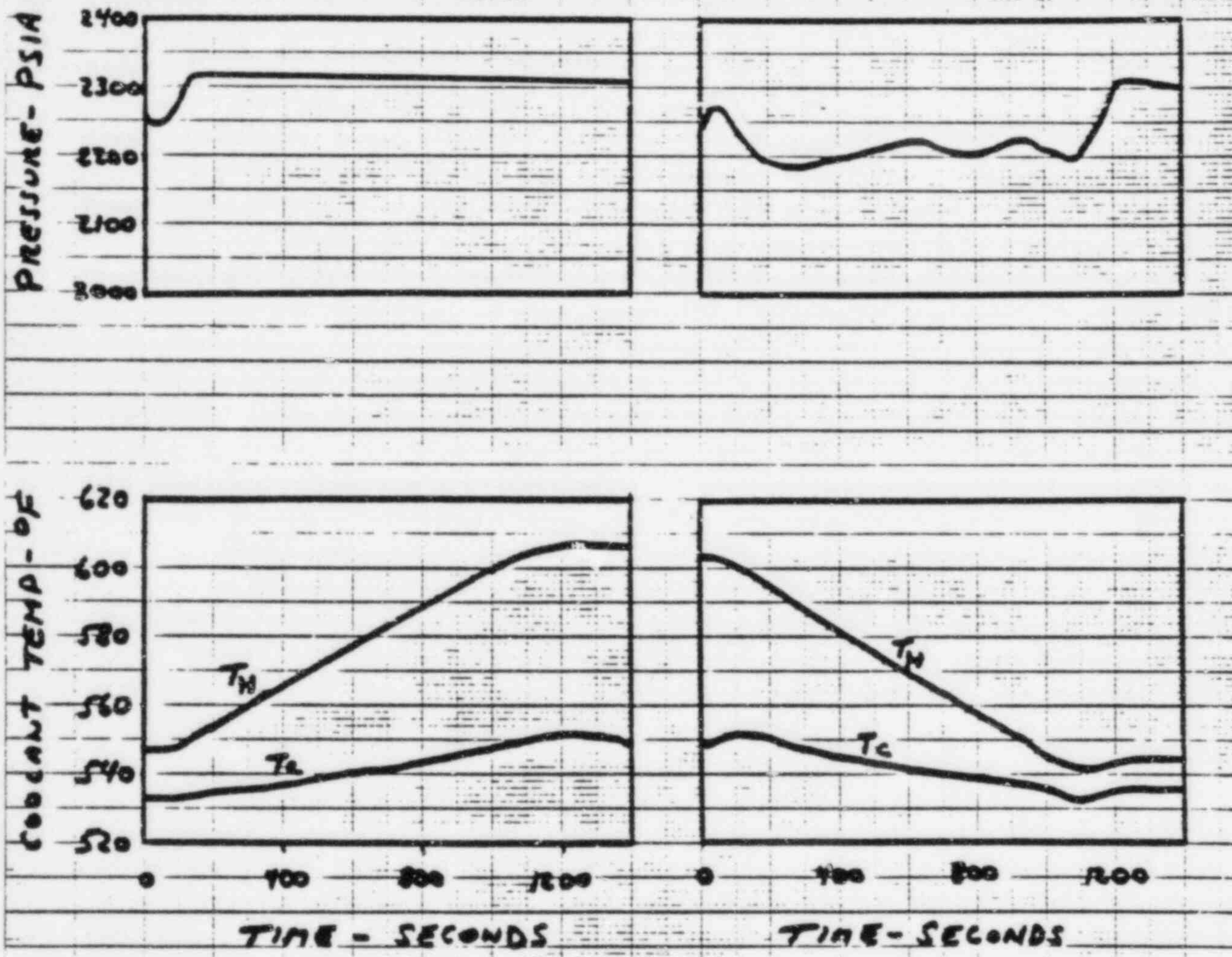


FIGURE 2

PLANT HEATUP & COOLDOWN

(TIME 0 SEC. REPRESENTS STEADY STATE CONDITIONS)

FIGURE 3



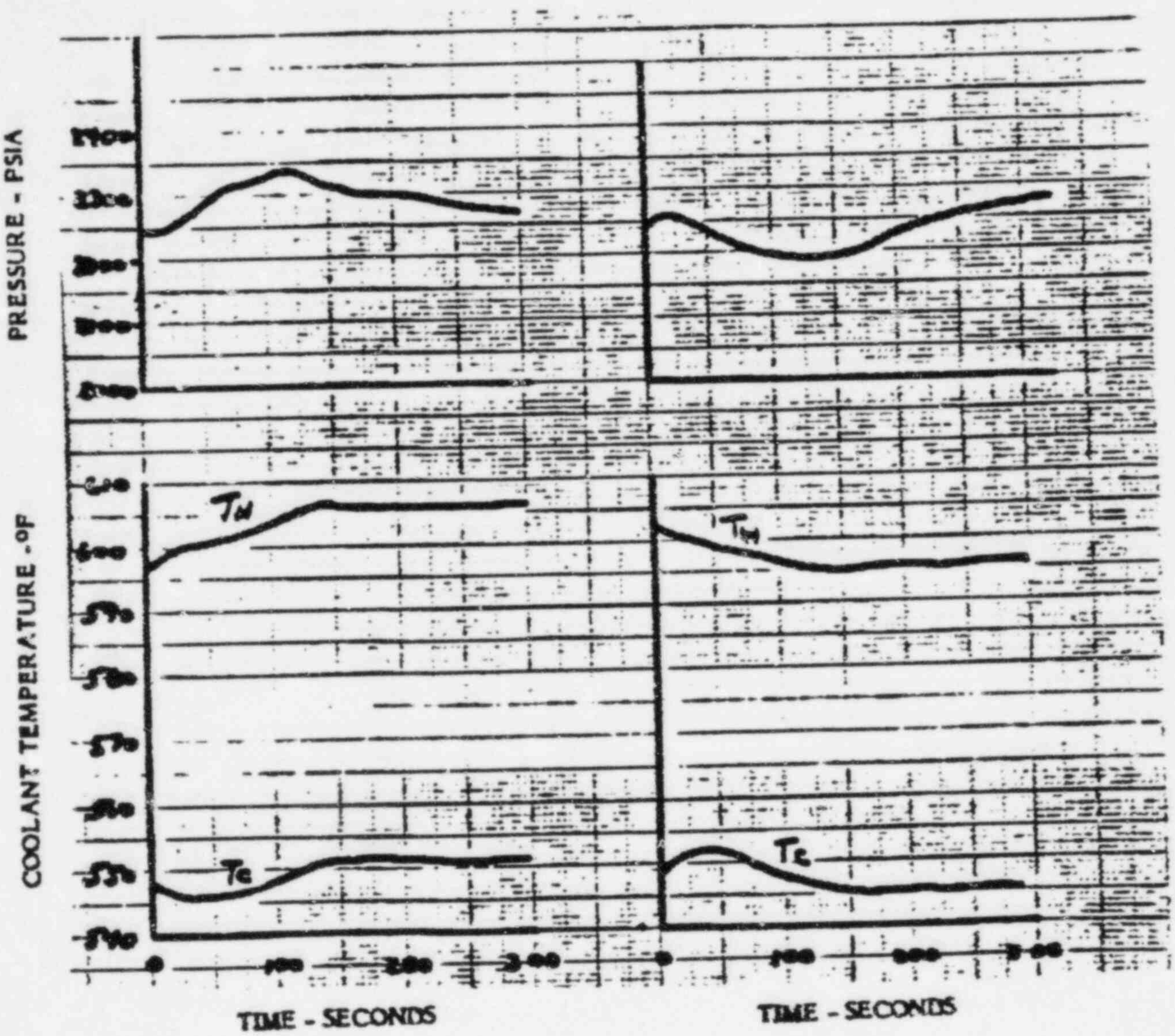
PLANT LOADING - 15 TO 100% PLANT UNLOADING 100 TO 15%

PLANT LOADING + UNLOADING
5% FULL LOAD / MINUTE

NOTES 1) TIME 0 Sec REPRESENTS STEADY STATE CONDITIONS

2) A GRADUAL RETURN TO STEADY STATE CONDITIONS MAY BE ASSUMED AT END OF TRANSIENT SHOWN

FIGURE 4



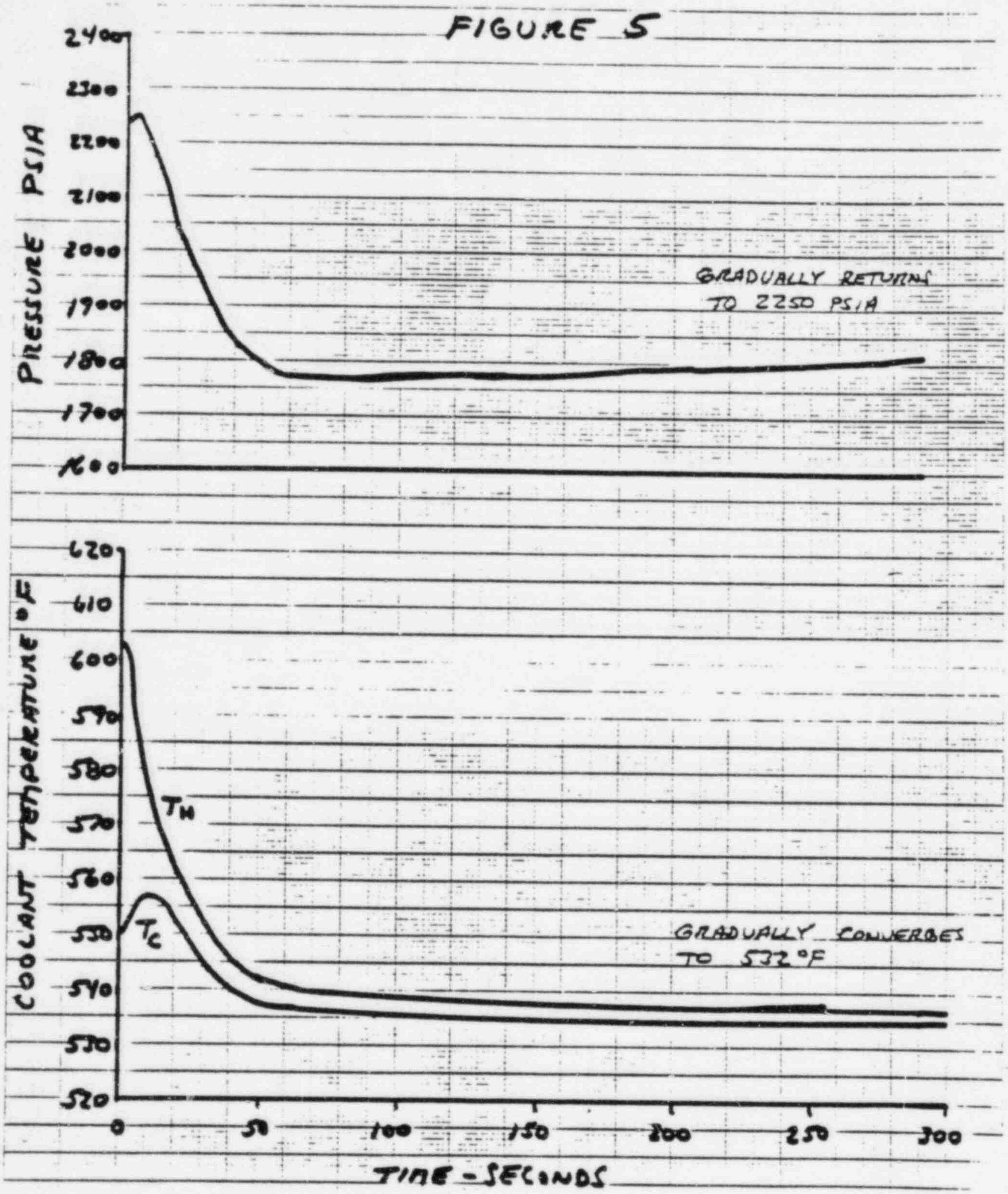
LOAD INCREASE FROM 90%

LOAD DECREASE FROM 100%

PLANT LOAD CHANGE - 10% FULL LOAD STEP

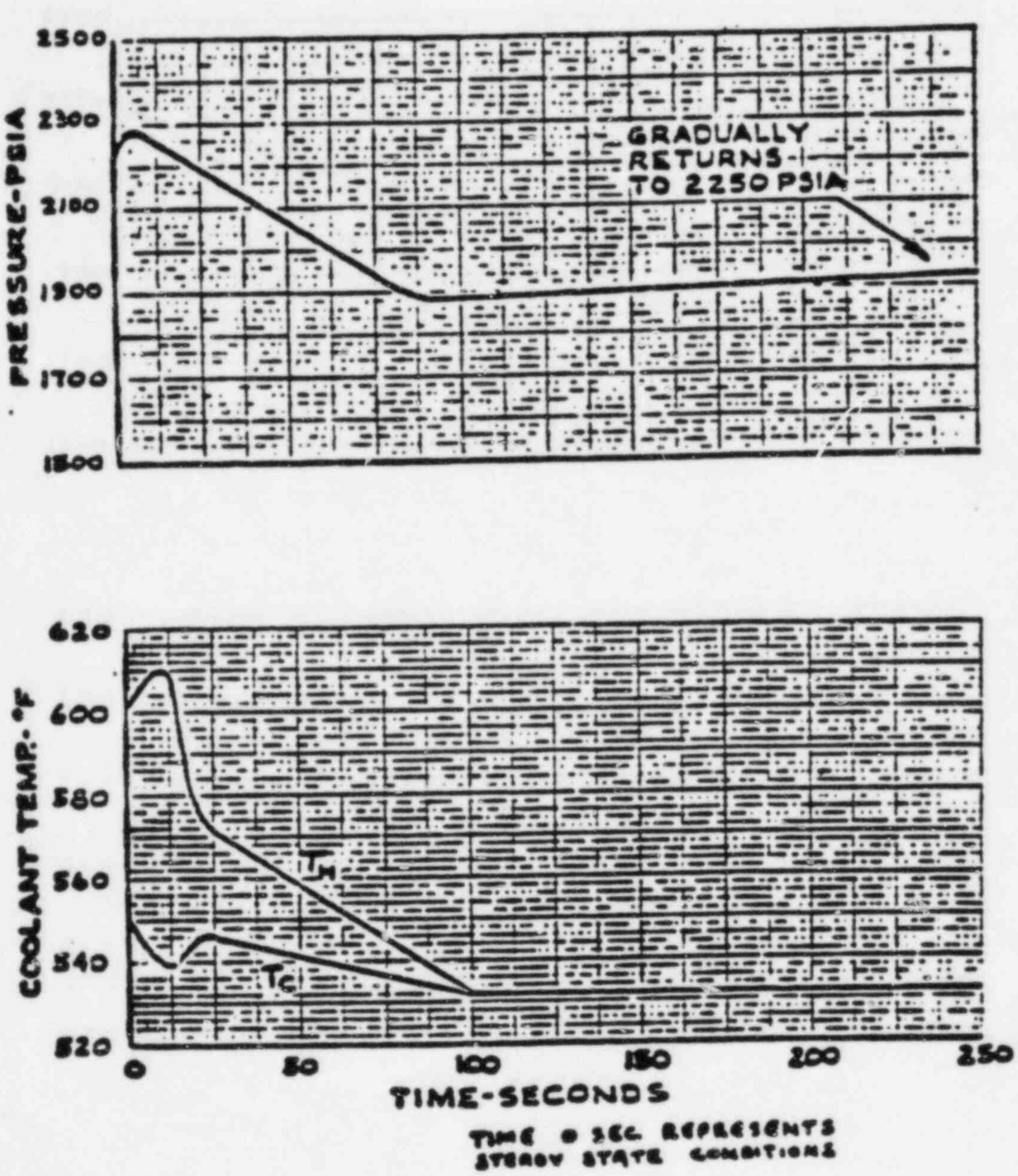
Notes:

1. Time 0 sec represents steady state conditions.
2. A gradual return to steady state conditions may be assumed at the end of transient shown.



REACTOR TRIP, LOSS OF LOAD

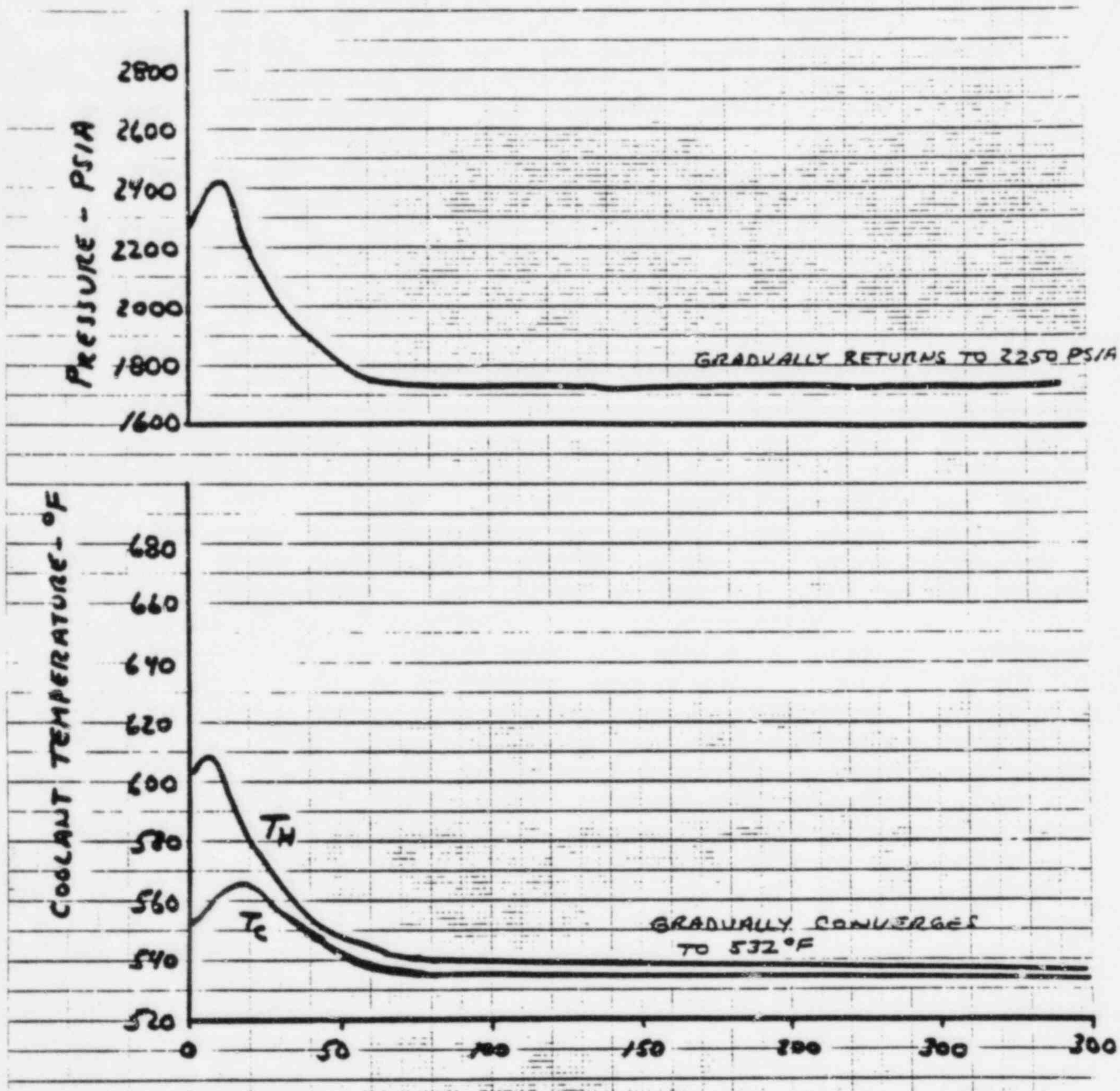
TIME 0 SEC REPRESENTS STEADY STATE CONDITIONS



LOSS OF FLOW

FIGURE 6

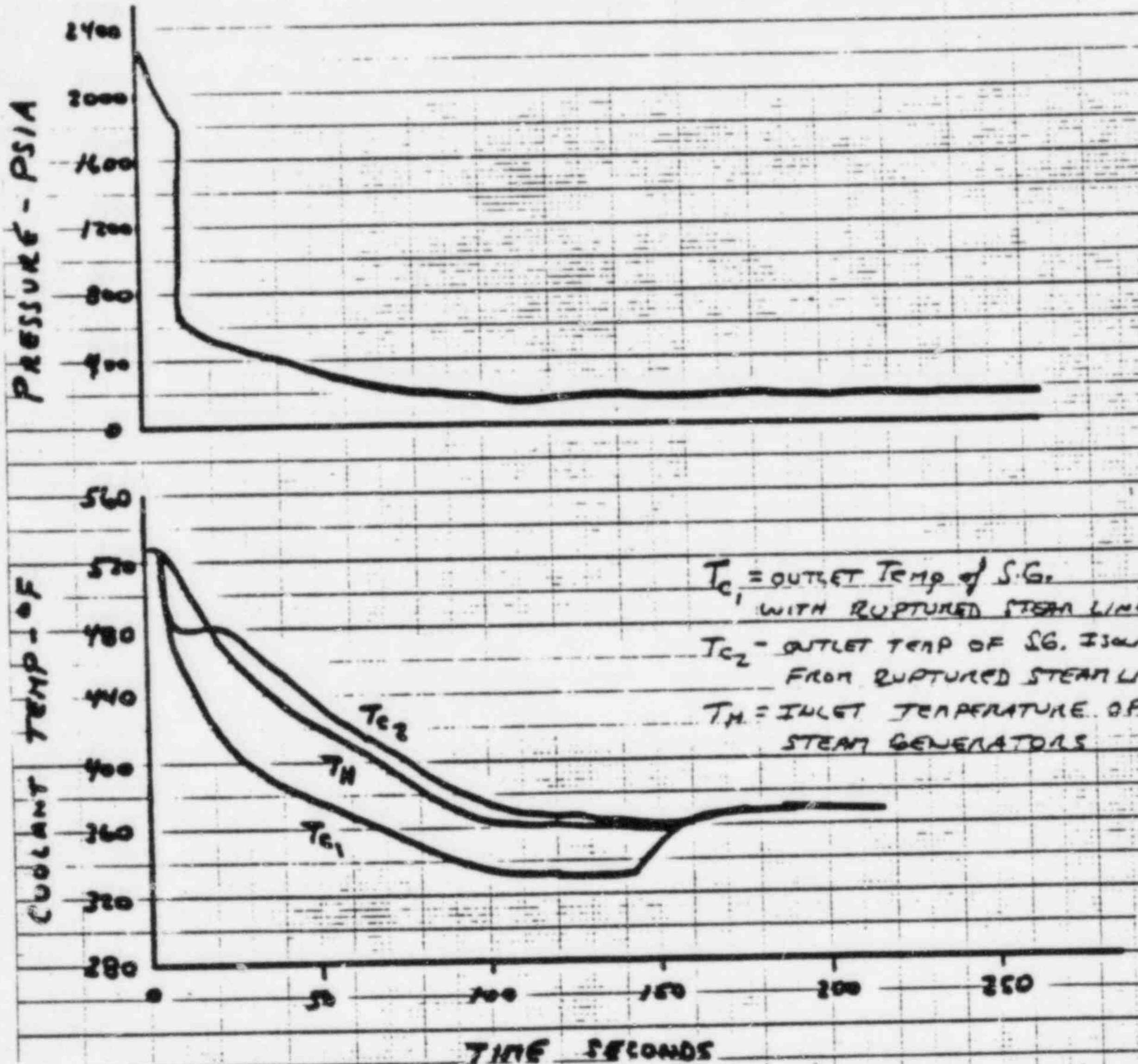
FIGURE 7



ABNORMAL LOSS OF LOAD

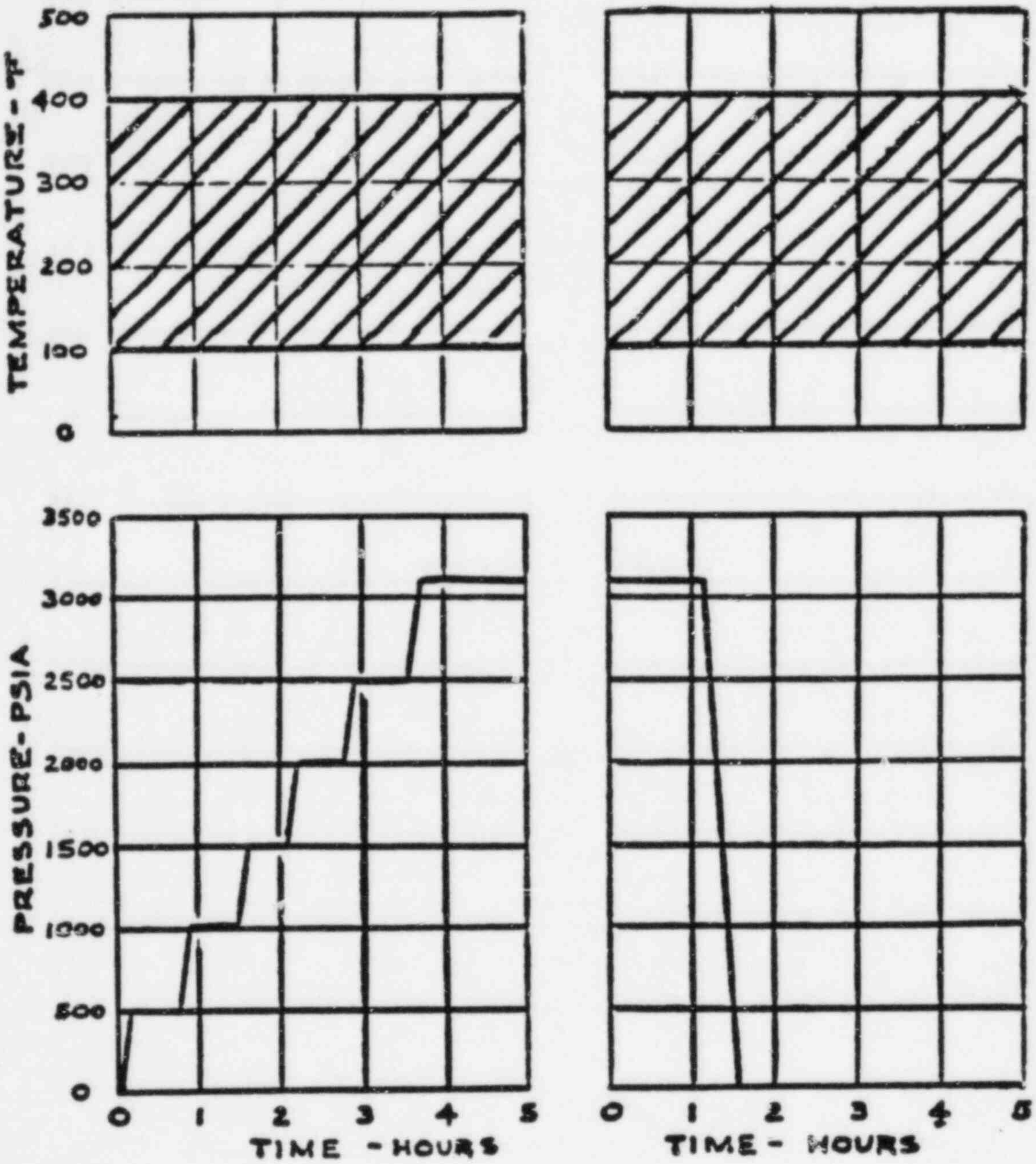
(TURBINE-GENERATOR TRIP WITH DELAYED REACTOR TRIP)

FIGURE 8



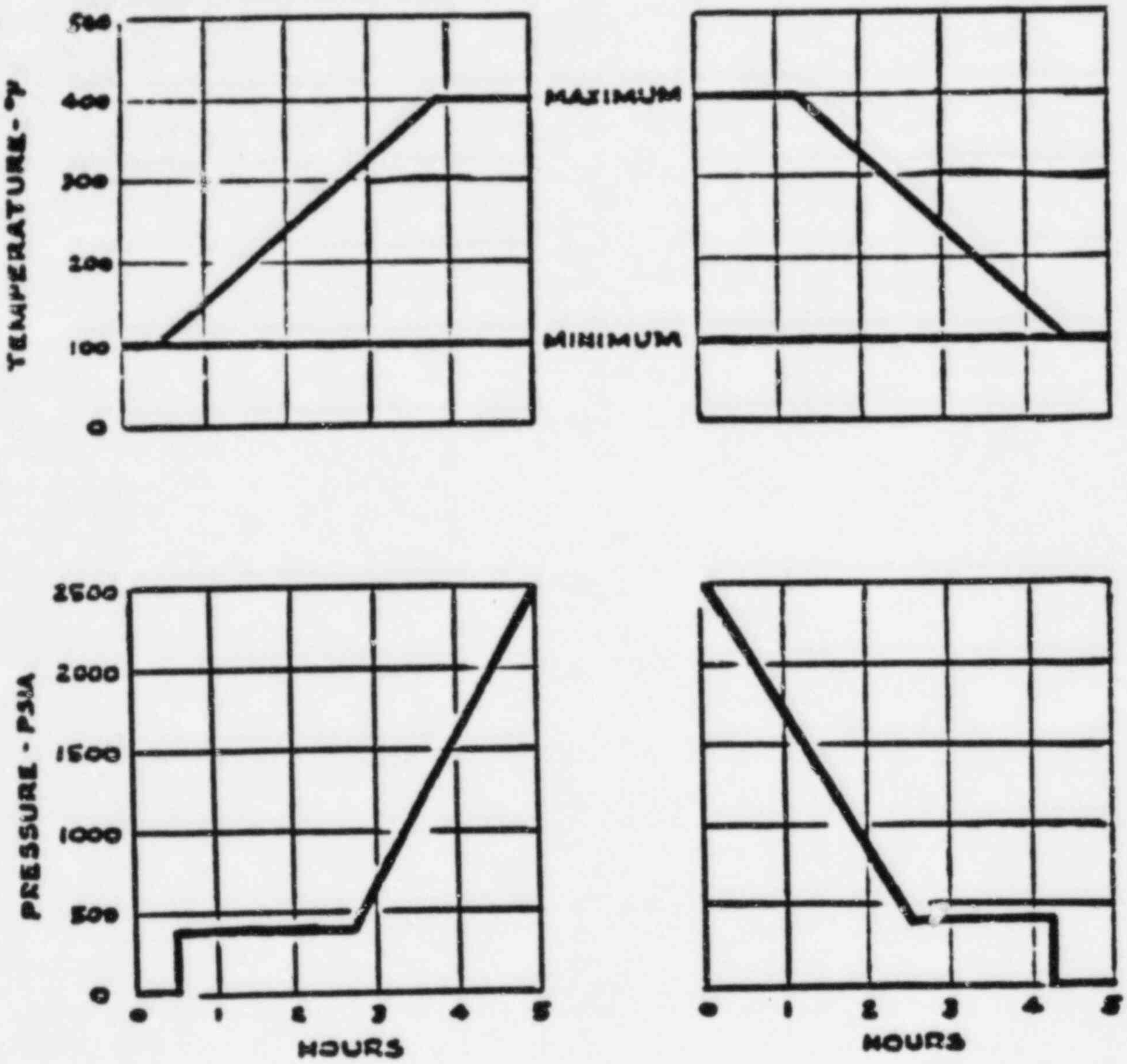
LOSS OF SECONDARY PRESSURE

NOTE: 1) TIME 0 SEC REPRESENTS STEADY STATE CONDITIONS
2) NORMAL PLANT COOLDOWN AT 100°F/HR IS INITIATED AT THE END OF THE TRANSIENT SHOWN
3) THE STEAM GENERATOR WITH THE RUPTURED STEAM LINE ISOLATED AND BOILS DRY AT TIME EQUALS 145 SEC.



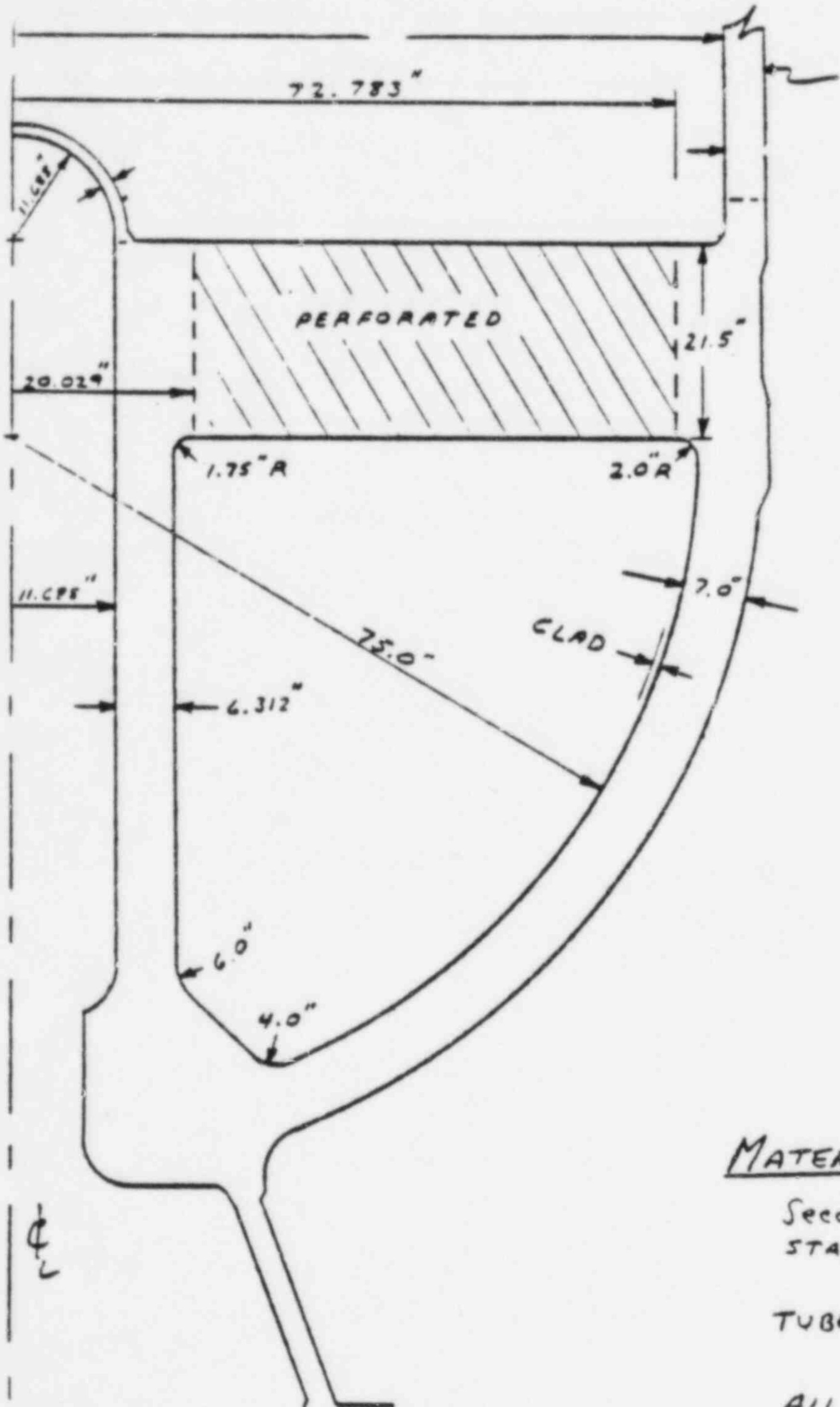
HYDROSTATIC TEST - 3125 PSIA

FIGURE 9



PLANT LEAK TEST 2500 PSIA

FIGURE 10



MATERIAL:

Secondary Shell } SA516,
Stay Cap } Gr 70

Tubesheet - SA 508
Class 2

All other SA 533, CL1
or equivalent

FIGURE 11

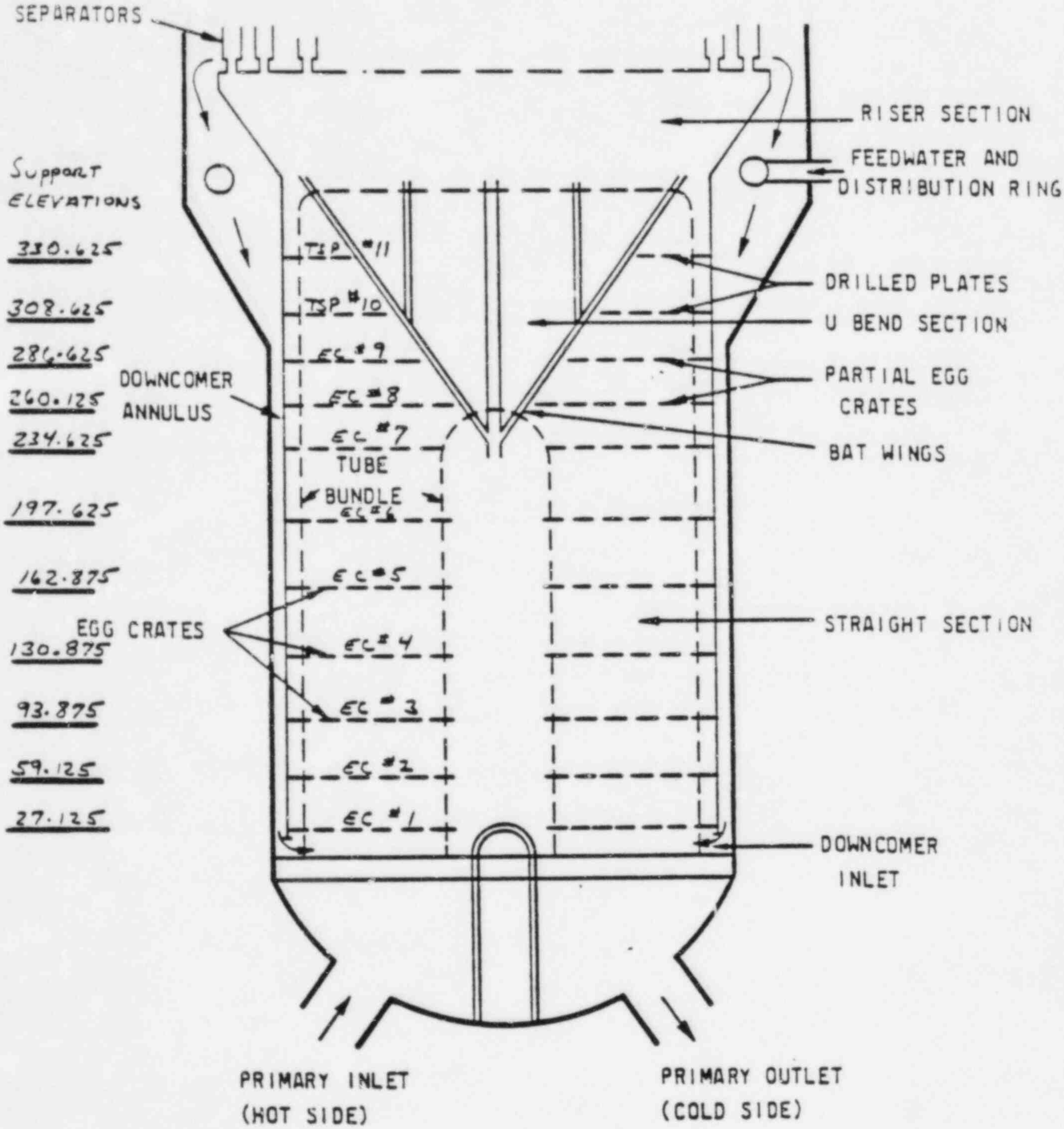


Figure 12 Schematic of SERIES 67 Steam Generator