REGULATORY INFORMATION DISTRIBUTION SYSTEM (RIDS)

ACCESSION NBR:8209080222 DOC.DATE: 82/08/31 NOTARIZED: NO DOCKET #
FACIL:50-244 Robert Emmet Ginna Nuclear Plant, Unit 1, Rochester G 05000244
AUTH.NAME AUTHOR AFFILIATION
MAIER,J.E. Rochester Gas & Electric Corp.
RECIP.NAME RECIPIENT AFFILIATION
CRUTCHFIELD,D. Operating Reactors Branch 5

SUBJECT: Forwards Revision 1 to proprietary, "Steam Generator Rapid Sleevig Program Design Verification Rept,RE Ginna Nuclear Power Plant," supporting installation of sleeves at facility.Rept withheld (ref 10CFR2.790).

SEE PROP. REPTS. #-8209080235

DISTRIBUTION CODE: A054S COPIES RECEIVED:LTR 1 ENCL 5 SIZE: 1+200
TITLE: OR Submittal: Steam Generator Sleeving Review for PWR's

NOTES:NRR/DL/SEP 1cy. Encls received. Withheld granted 3/22/83 05000244

	RECIPIENT ID CODE/NAME		COPIES LTTR	ENCL	RECIPIENT ID CODE/NAME		COPIES LTTR	ENCL
	NRR ORB5 BC	01	3	3				
INTERNAL:	AEOD	16	1	0	ELD/HDS4	13	1	0
	IE	13	1	0	NRR/DE/CEB	08	1	0
	NRR/DE/EEB	12	1	0	NRR/DE/MEB	06	1	0
	NRR/DE/MTEB	05	1	0	NRR/DL/ORAB	10	1	0
	NRR/DSI/AEB	09	1	0	NRR/DSI/ETSB	11	1	0
	NRR/DSI/RAB	07	2	0	~~REG FILE~~	03	1	1
	RGN1	12	1	0				
EXTERNAL:	ACRS	17	10	0	LPDR	04	1	0
	NRC PDR	02	1	0	NSIC	14	1	0
	NTIS	15	1	0				
NOTES:			1	1				

TOTAL NUMBER OF COPIES REQUIRED: LTTR 32 ENCL ~~32~~ 28

ROCHESTER GAS AND ELECTRIC CORPORATION • 89 EAST AVENUE, ROCHESTER, N.Y. 14649

JOHN E. MAIER
Vice President

TELEPHONE
AREA CODE 716 546-2700

August 31, 1982

Director of Nuclear Reactor Regulation
Attention: Mr. Dennis M. Crutchfield, Chief
Operating Reactors Branch No. 5
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Subject: Steam Generator Sleeving
R. E. Ginna Nuclear Power Plant
Docket No. 50-244

Dear Mr. Crutchfield:

In our letter dated January 15, 1982, we indicated our intention to proceed with the licensing of sleeving for the Ginna Station steam generators. At that time, we submitted a proposed revision to the Ginna Inservice Inspection Program. We also described our intention to complete all required documentation, to conduct reviews of the design by our on-site and off-site Safety Review Boards, and to convene a Design Review Board to conduct an independent review.

The required analysis and safety evaluation supporting installation of sleeves at Ginna is enclosed. This report is proprietary to Babcock and Wilcox. Therefore, pursuant to 10 CFR 2.790(b), we request that it be withheld from public disclosure. An affidavit supporting non-disclosure is enclosed.

Our on-site and off-site reviewers are scheduled to perform their reviews in the near future.

As discussed with you and your Staff, a Design Review Board is scheduled to perform its review during a meeting September 15 and 16, 1982 at the Babcock and Wilcox facilities in Lynchburg, Virginia. The majority of the meeting will be closed, since information will be discussed which is proprietary to Babcock and Wilcox. A transcript will be kept which will be submitted to the NRC.

Very truly yours,

John E. Maier

John E. Maier

Attachments

A054
1/5 Encls Rec'd

Change:
PDR
LPDR
NSIC
NTIS } Ltr Only

40

Babcock&Wilcox

AFFIDAVIT OF JAMES H. TAYLOR

A. My name is James H. Taylor. I am Manager of Licensing in the Nuclear Power Generation Division of Babcock & Wilcox, and as such I am authorized to execute this Affidavit.

B. I am familiar with the criteria applied by Babcock & Wilcox to determine whether certain information of Babcock & Wilcox is proprietary and I am familiar with the procedures established within Babcock & Wilcox, particularly the Nuclear Power Generation Division (NPGD), to ensure the proper application of these criteria.

C. In determining whether a Babcock & Wilcox document is to be classified as proprietary information, an initial determination is made by the unit manager who is responsible for originating the document as to whether it falls within the criteria set forth in Paragraph D hereof. If the information falls within any one of these criteria, it is classified as proprietary by the originating unit manager. This initial determination is reviewed by the cognizant section manager. If the document is designated as proprietary, it is reviewed again by Licensing personnel and other management within NPGD as designated by the Manager of Licensing to assure that the regulatory requirements of 10 CFR Section 2.790 are met.

D. The following information is provided to demonstrate that the provisions of 10 CFR Section 2.790 of the Commission's regulations have been considered:

(i) The information has been held in confidence by the Babcock & Wilcox Company. Copies of the document are clearly identified as proprietary. In addition, whenever Babcock & Wilcox transmits the information to a customer, customer's agent, potential customer or regulatory agency, the transmittal requests the recipient to hold the information as proprietary. Also, in order to strictly limit any potential or actual customer's use of proprietary information, the following

provision is included in all proposals submitted by Babcock & Wilcox, and an applicable version of the proprietary provision is included in all of Babcock & Wilcox's contracts:

"Purchaser may retain Company's Proposal for use in connection with any contract resulting therefrom, and, for that purpose, make such copies thereof as may be necessary. Any proprietary information concerning Company's or its Suppliers' products or manufacturing processes which is so designated by Company or its Suppliers and disclosed to Purchaser incident to the performance of such contract shall remain the property of Company or its Suppliers and is disclosed in confidence, and Purchaser shall not publish or otherwise disclose it to others without the written approval of Company, and no rights, implied or otherwise, are granted to produce or have produced any products or to practice or cause to be practiced any manufacturing processes covered thereby.

Notwithstanding the above, Purchaser may provide the NRC or any other regulatory agency with any such proprietary information as the NRC or such other agency may require; provided, however, that Purchaser shall first give Company written notice of such proposed disclosure and Company shall have the right to amend such proprietary information so as to make it non-proprietary. In the event that Company cannot amend such proprietary information, Purchaser shall, prior to disclosing such information, use its best efforts to obtain a commitment from NRC or such other agency to have such information withheld from public inspection.

AFFIDAVIT OF JAMES H. TAYLOR (Cont'd)

Company shall be given the right to participate in pursuit of such confidential treatment."

(ii) The following criteria are customarily applied by Babcock & Wilcox in a rational decision process to determine whether the information should be classified as proprietary. Information may be classified as proprietary if one or more of the following criteria are met.

a. Information reveals cost or price information, commercial strategies, production capabilities, or budget levels of Babcock & Wilcox, its customers or suppliers.

b. The information reveals data or material concerning Babcock & Wilcox research or development plans or programs of present or potential competitive advantage to Babcock & Wilcox.

c. The use of the information by a competitor would decrease his expenditures, in time or resources, in designing, producing or marketing a similar product.

d. The information consists of test data or other similar data concerning a process, method or component, the application or which results in a competitive advantage to Babcock & Wilcox.

e. The information reveals special aspects of a process, method, component or the like, the exclusive use of which results in a competitive advantage to Babcock & Wilcox.

f. The information contains ideas for which patent protection may be sought.

AFFIDAVIT OF JAMES H. TAYLOR (Cont'd)

The document(s) listed on Exhibit "A", which is attached hereto and made a part hereof, has been evaluated in accordance with normal Babcock & Wilcox procedures with respect to classification and has been found to contain information which falls within one or more of the criteria enumerated above. Exhibit "B", which is attached hereto and made a part hereof, specifically identifies the criteria applicable to the document(s) listed in Exhibit "A".

(iii) The document(s) listed in Exhibit "A", which has been made available to the United States Nuclear Regulatory Commission was made available in confidence with a request that the document(s) and the information contained therein be withheld from public disclosure.

(iv) The information is not available in the open literature and to the best of our knowledge is not known by Combustion Engineering, EXXON, General Electric, Westinghouse or other current or potential domestic or foreign competitors of B&W.

(v) Specific information with regard to whether public disclosure of the information is likely to cause harm to the competitive position of Babcock & Wilcox, taking into account the value of the information to Babcock & Wilcox; the amount of effort or money expended by Babcock & Wilcox developing the information; and the ease or difficulty with which the information could be properly duplicated by others is given in Exhibit "B".

E. I have personally reviewed the document(s) listed on Exhibit "A" and have found that it is considered proprietary by Babcock & Wilcox because it contains information which falls within one or more of the criteria enumerated in Paragraph D, and it is information which is customarily held in confidence and protected as proprietary information by Babcock & Wilcox. This report comprises information utilized by Babcock & Wilcox in its business which afford Babcock & Wilcox an opportunity to obtain a competitive advantage over

those who may wish to know or use the information contained in the document(s).

James H. Taylor

JAMES H. TAYLOR

State of Virginia)
) SS. Lynchburg
City of Lynchburg)

James H. Taylor, being duly sworn, on his oath deposes and says that he is the person who subscribed his name to the foregoing statement, and that the matters and facts set forth in the statement are true.

James H. Taylor

JAMES H. TAYLOR

Subscribed and sworn before me
this 26 day of August 1982.

Danita R. Kidd

Notary Public in and for the City
of Lynchburg, State of Virginia
Commissioned Notary as
Danita D. Robertson

My Commission Expires July 1, 1983

EXHIBIT A

STEAM GENERATOR RAPID SLEEVING PROGRAM

DESIGN VERIFICATION REPORT

R.E. GINNA NUCLEAR POWER PLANT

EXHIBIT B

STEAM GENERATOR RAPID SLEEVING PROGRAM

R.E. Ginna Nuclear Power Plant

Proprietary Nature of Material

Description of Material	Applicable Criteria
The following sections of the document identified above and in Exhibit A contain proprietary information in text and figures	
Section 2.0 Summary	b,c,d,e & f
Section 4.0 Program Description	b,c,d,e & f
Section 5.0 Design Criteria	b,c,d & e
Section 6.0 Sleeving Design	b,c,d,e & f
Section 7.0 Testing	b,c,d & e
Section 8.0 Analysis	b,c,d & e
Section 9.0 Installation	b,c,d,e & f
Section 10.1.1 Test Sleeve Eddy Current Inspection	b,c,d & e
Section 10.1.2 Rapid Sleeving Eddy Current Inspection	
Paragraphs under System Description	b,c,d & e
Section 10.2 Steam Generator Tube/Sleeve Ultrasonic Inspection System	
Paragraphs:	
System Description	b,c,d,e & f
Operation	b,c,d,e & f

STEAM GENERATOR RAPID SLEEVING PROGRAM

R. E. Ginna Nuclear Power Plant

Design Verification Report

(B&W/RG&E Proprietary)

August 27, 1982

Revision 01

Babcock and Wilcox
Nuclear Power Group
Nuclear Power Generation Division
P.O. Box 1260
Lynchburg, Virginia 24505-1260

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

1.0 INTRODUCTION

1.1 General Background

Until recently, a steam generator tube with an eddy current indication exceeding that stipulated by the plant's Technical Specification was removed from service by plugging. Plugging more than about .5% of the total number of tubes (~3,000) in a nuclear steam generator per year ultimately will result in either reducing the power generating capacity of the plant or entirely replacing the steam generators. Since many utility-owned nuclear power plants are experiencing defective steam generator tubes, a technique for keeping tubes in service is an important cost-effective advancement.

By intent, such a technique would keep "pluggable" steam generator tubes in service. By design, such a method must also:

- o Act as a new primary pressure boundary over an area in and immediately above the steam generator tubesheet, where most of the corrosive, defect-initiating attack occurs,
- o Resist the mechanism(s) initiating the attack,
- o Withstand the conditions the generator will experience during the remainder of its life,
- o Use an installation procedure that maintains as low as reasonably achievable (ALARA) radiation exposure to working personnel.

The technique developed by Babcock & Wilcox (B&W) for Rochester Gas & Electric (RG&E) to keep tubes with pluggable eddy current indications in service is the sealable sleeve. The sealable sleeve, discussed in this report, forms a new pressure boundary by spanning the defect indication in the tube and forming a leak-tight seal between each end of the sleeve and the sound tube material. Further, the material was selected to resist the caustic intergranular attack (IGA) from the secondary side of the nuclear steam generator at RG&E's Ginna Plant. Particular attention was paid to the way the sleeve is attached to the sound tube -- that is, the sleeve is "cold-worked" as little as possible to minimize potential stress-corrosion-cracking (SCC) defects and maintain the heat-treating effects of the Inconel core material.

Twenty-one sleeves have been installed at the Ginna Plant, with the last sleeve taking only 2 1/2 hours to put in place with a personnel exposure of one man-rem. Tooling for the sleeving process has been developed that will allow 30 sleeves per day to be installed with an exposure of less than .25 man-rem per sleeve.

1.2 Scope of the Report

The objective of this Design Verification Report is to provide sufficient information to illustrate that the sealable sleeve used at RG&E's Ginna Nuclear Station complies with the applicable codes and safety standards governing the licensing and operation of the plant. Information presented in this document include: the background behind the necessity for sleeving at Ginna (section 3.0), a description of the B&W/RG&E sealable sleeve program (section 4.0); the criteria for, a description of, and the analysis and testing of the sealable sleeve design (sections 5 through 8); a discussion of the tooling, installation and qualifying processes including man-rem exposure considerations (section 9.0). Sections 10 and 11 respectively present information on the ease of inspecting installed sleeves and the safety evaluations performed for the sleeving methodology.

The sleeves that have been developed are being evaluated in three ways: 1) testing 2) analyses, and 3) operating performance.

- o <u>Testing</u> (section 7.0) includes:
  Fatigue Load Testing for the upper and lower joints, testing the leak rate of non-bonded sleeve, assessing the corrosion resistance of the bimetallic sleeving material, and evaluating the ability of the sleeve to withstand hydrostatic pressure.

- o <u>Analyses</u> (section 8.0) performed:
  Considered normal, faulted, and seismic operating conditions, vibrational suitability, plugging limits, and compliance of the design with code requirements.

- o <u>Operating Performance</u> includes:
  Monitoring the performance of the five and 16 test specimens (sleeves) currently in place at the Ginna Station.

2.0 SUMMARY

An innovative way to keep defective nuclear steam generator tubes inservice has been developed. This method involves a sleeve that becomes a new primary pressure boundary by spanning the defect in the tube and forming a leak-tight seal between each end of the sleeve and the sound tube material.

The sealable sleeve developed by B&W for RG&E has been designed to resist IGA, and therefore, has an inner core of thermally-treated Inconel co-extruded with an outer sheath of nickel. The Inconel core is compatible with the original tubing material and primary fluid, while the outer nickel layer provides resistance against IGA. Further, the method used to install the sleeves requires minimal cold-working and thus minimizes the potential for induced SCC. The upper end of the sleeve is explosively expanded and then sealed to the sound tubing material with an induction brazing technique that uses a gold alloy. The lower end of the sleeve is welded to the tube by an explosive charge. The installation process uses remotely-controlled tooling to minimize personnel radiation exposure. Tooling tests illustrate that sleeves can be installed at a rate greater than 30 per day with an average radiation exposure of less than 0.177 Rem per sleeve for 100 sleeves installed.

Analyses of the sleeve design have shown that the sleeve is as strong as the original tubing. In addition the sleeve meets all the required design requirements and is qualified as a primary pressure boundary.

Using loads developed in the analysis, the upper and lower joints were fatigue tested. The results demonstrate that the sleeve can accept the design loadings without failure or leakage. In addition, the expanded mechanical upper joint without braze was demonstrated to meet the design structural loads, as a back up to the braze joint. Leak testing of an expanded mechanical joint demonstrates that the measured leak rates are extremely low.

To date, 21 test sleeves have been installed at Ginna Station: five of a nickel-plated/inconel design, and 16 using a nickel/inconel co-extruded design. The integrity of the installed sealable sleeve and the parent tube containing the sleeve are inspected both before and after operation using non-destructive eddy current technique. The five nickel-plated/inconel sleeves have seen 18 months of service; the 16 co-extruded sleeves, 12 months -- examinations indicate that the sleeves are performing well.

3.0 BACKGROUND FOR THE GINNA PLANT AND PROBLEM IDENTIFICATION

Ginna Station is a Westinghouse designed, two-loop pressurized water reactor (PWR) owned by Rochester Gas & Electric. It is licensed to operate 1520 megawatts thermal (MWt) and has a net electrical capacity of 490 megawatts.

The two steam generators are Westinghouse series, 44 vertical shell and U-tube units, each rated at 3,130,000 lbs/hr steam flow at 725 psig. The steam generator tubing is Inconel 600 (SB-163-61T). The tubes are partially rolled into the tubesheet and seal welded.

Since concentrations of material deposited in the crevice between the tube sheet and tube during normal opration are believed to contribute to tube failure a brief account of the secondard water chemistry practices at the Ginna Station are given. Phosphate secondary water chemistry control was used from startup through November, 1974. In December, 1974, secondary water chemistry control was converted to all volatile treatment (AVT). AVT was maintained through condenser integrity and steam generator blowdown until December, 1977. From January, 1978 until the present, full flow, deep bed condensate demineralizers have been in operation.

Steam generator tube wastage, caustic cracking, and ID cracking have been experienced at Ginna. Between March 1974 and October 1980, 121 tubes were plugged in the A- and 68 in the B-steam generators for these reasons. During the spring of 1979 refueling outage, the first indications of OD intergranular attack (IGA) of tubes in the tubesheet crevice region were discovered. In December, 1979, 11 tubes were plugged in the B-steam generator due to IGA conditions; an additional 31 tubes were plugged in March, 1980.

Twenty-one tubes having IGA conditions have been repaired with total of 112 tubes (3.4%) having now been plugged in the B-steam generator. No IGA indications have yet been discovered in the A-steam generator. All of the IGA indications to date have been below the top of the tubesheet and above the expanded area at the tube end. In addition, all of the indications have been in the hot leg tubes.

The IGA appears to be a caustic stress corrosion phenomenon. Since the spring of 1980, Rochester Gas & Electric has initiated several programs dedicated to resolving this problem. These programs have included more extensive eddy current examinations, crevice flushing, water lancing, tube pulling, laboratory testing, and sleeving.

The sleeving development program was initiated by Rochester Gas & Electric with Babcock & Wilcox in July, 1980. The primary objective of the program was to develop a sealable sleeve suitable for a service life of no less than 30 years in the crevice environment. Equipment and tooling were developed to allow sleeving as a permanent fix for tubesheet IGA on a schedule consistent with normal plant operation and refueling outages. Sleeving is intended both as an alternative repair technique to plugging and as a preventive maintenance procedure.

The installation of five nickel-plated/Inconel bimetallic test sleeves during the November, 1980 outage demonstrated the technical adequacy of the basic sleeve design and installation processes. However, the tooling, equipment, and procedures used were not designed to install a large number of sleeves in a reasonable time with an acceptable amount of radiation exposure.

At the outage in May, 1981, 16 nickel/Inconel co-extruded bimetallic sleeves were installed in the B-steam generator. The co-extruded bimetallic sleeve differs from the previously installed nickel-plated sleeve only in that the outer nickel layer is diffusion bonded over the entire length of the Inconel core as an integral part of the tube making process. This improved product allows the nickel layer to be carried into the upper end attachment, thus providing a continuous barrier to secondary side caustic attack. Fourteen sleeves were

installed in tubes that would otherwise have been plugged. The average rate of installation was three sleeves per day with an average exposure of 3.2 man-rem per sleeve. Initial problems with the new tooling precluded installing of five to ten sleeves per day -- the installation rate goal. However, the last sleeve was installed in 2-1/2 hours with an exposure of only one man-rem. This performance indicated that once the tooling problems were resolved, the original installation objectives could be met.

From the experience with IGA at Ginna and at other utilities, the necessity to develop a rapid sleeving methodology was apparent. Plugging or sleeving large numbers of steam generator tubes per outage may be required. It is clear that an effort must be made to install sleeves at a rate exceeding five to ten per day. Current industry developments indicate that an installation rate exceeding 20 sleeves per day is desirable. To achieve this goal, an integrated approach to process and tool modifications was required.

The RG&E Rapid Sleeving Program is capable of installing 30 sleeves per day over a 30-day period with a projected exposure of less than .25 man-rem per sleeve.

4.0 PROGRAM DESCRIPTION

The program to develop a sealable sleeve for the Rochester Gas & Electric Company by Babcock & Wilcox comprised three phases: Development, Design Verification, and Implementation. The first two phases are complete; the third will be in the spring of 1983 and is anticipated to extend over several years. The three phases are individually discussed in the ensuing pages.

4.1 Development

This phase involved the preliminary work to establish and test a viable sleeve design. In addition to such considerations as sleeving material and strength of the seal welds, the impact of installing sleeves on outage schedules was investigated -- the objective being to install the sleeve during normal outage maintanance. The sleeving material was selected based on compatability with design steam generator tube and primary coolant, and resistance to IGA prevalent in the Ginna plant. Specific procedure and tooling concepts were developed for the Verification Phase. Finally, five nickel-plated test sleeves were installed at Ginna in November 1980 to demonstrate the adequacy of the sleeve design.

4.2 Design Verification

During this phase, additional laboratory testing and analysis and qualification work were performed to demonstrate that sleeving is a viable technique for repairing steam generator tubes. Sixteen bimetallic sleeves were installed in the Ginna B-steam generator in the spring of 1981 to verify the field adequacy of the manual installation procedures. Experience from this installation, together with recent industry developments that have seen rapid deterioration of steam generator tubes has led to the realization that a rapid sleeve installation rate was necessary so that tube repair and preventative

sleeving can be accomplished during the normal maintenance outages. Therefore the Rapid Sleeving Program was initiated to optimize the installation process and develop automatic remote installation tools leading to the Implementation Phase.

4.3 Implementation

Rochester Gas and electric intends to implement the rapid sleeving techique as a standard steam generator tube repair procedure. In addition, RG&E plans to preventatively sleeve approximately 1600 tubes in each steam generator over the next several years. This preventative sleeving program is scheduled to begin in the spring 1983 and will continue during each steam generator inspection until all accessible tubes potentially subject to degradation have been sleeved.

5.0 DESIGN CRITERIA

The design criteria for steam generator tube sleeves at the RG&E Ginna Station is "Design Criteria - Ginna Station - Steam Generator Tube Sleeves - EWR 2714F - Revision 2". A summary of the design criteria contained in this document is as follows:

5.1 Function

5.1.1 The steam generator sleeve design parameters are provided in Tables 5-1 and 5-2.

5.1.2 The steam generator sleeves are a sealable design intended to extend the life of the Westinghouse series 44 vertical shell U-tube steam generators experiencing crevice cracking. (See Section 6.0 for Sleeve Design).

5.1.3 The sealable sleeve design is a thin wall tube capable of being attached to the steam generator tube I.D. Sleeve length may vary between 24 and 36 inches depending on space available for access. (See Section 6.0 for Sleeve Design).

5.1.4 The existing steam generator tubes at Ginna are 0.875 inch OD X 0.050 inch average wall. The lower 2-3/4 inches of each tube are rolled into 0.888 to 0.893 inch diameter holes in a 22-inch thick tubesheet. (See Section 6.0 for Sleeve Design).

5.1.5 The sleeve material is compatible with the primary and secondary system environment and the existing steam generator materials. The sleeve material has been selected to optimize the mechanical design and maximize the resistance to intergranular attack during the lifetime of the unit. Corrosion resistance of the sleeve including brazing material is equal to or better than the original tube material.(See Section 6.0 for Sleeve Design and Section 7.0 for testing).

5.2 Performance Requirements

The steam generator sleeve design parameters are given in Tables 5-1 and 5-2.

5.2.1 The primary side of each steam generator is designed for a pressure of 2485 psig and a temperature of 650°F. The secondary side is designed for a pressure of 1085 psig and 600°F. (See Section 8.0 for Analysis).

5.2.2 The sleeves are designed such that the reduction in primary flow through the sleeved tube caused by the increased flow resistance has a minimal effect on the thermal/hydraulic characteristics of the steam generator. (See Section 8.0 for Analysis).

5.2.3 The upper sleeve-to-tube connection is brazed. The lower connection is explosively welded. (See Section 6.0 for Design).

The method and technique used to attach the sleeve does not affect the tubesheet-to-clad bond. Note: The Ginna SG cladding was applied using the DETA-CLAD process.

5.2.4 The sleeving installation meets the same design requirements (i.e., vibration, pressure temperature) as the original tube. (See Section 8.0 for Analysis).

5.2.5 Sleeving has a negligible influence on the applied dynamic stresses on the tube. (See Section 8.0 for Analysis).

5.2.6 The sleeve design allows plugging, in the event the sleeve fails in service. (See Section 6.0 for Design).

5.2.7 Installation of the sleeve shall not adversely affect the pressure retaining function or the structural integrity of the tube or tubesheet. (See Section 8.0 for Analysis).

5.2.8 The design is adaptable to remote, rapid installation. (See Section 9.0 for Installation).

5.2.9 Brazing, welding and expansion systems leaves no unacceptable residue in the steam generator. (See Section 6.0 for Design).

5.2.10 Tube-to-sleeve welds do not contact the tube-to-tubesheet welds. (See Section 6.0 for Design).

5.2.11 The sleeve is designed so that it is possible to detect defects of the same type and size in a sleeved section of tubing as the original tubing. (See Section 10.0 for Inspectability).

5.3 Control

Not Applicable

5.4 Modes of Operation

The sleeve does not operate in various modes since it has no moving parts. However, it will be subjected to various operating or transient conditions during the lifetime of the unit. For design purposes, the thermal and loading cycles are given in Table 5-3. (See Section 8.0 for Analysis).

5.5 Referenced Documents

The following documents are referenced herein. Their applicability or requirements for design are as specified in other sections of this criteria document.

5.5.1 USNRC Regulatory Guides

A. No. 1.26, "Quality Group Classifications and Standards For Water, Steam, and Radiowaste Containing Components for Nuclear Power Plants," Rev. 3, February 1976.

B. No. 1.29, "Seismic Design Classification," Rev. 3, September 1978.

5.5.2 American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code - 1980 Edition
Section II - "Material Specifications"
Section III - "Nuclear Power Plant Components"
Section XI - "In-Service Inspection"
Section IX - "Welding and Brazing Qualifications"

5.5.3 Ginna Station Final Facility Description and Safety Analysis Report (FSAR).

5.5.4 Technical manual 1440-C88, April, 1968, "Vertical Steam Generator For RG&E Corporation, R.E. Ginna Nuclear Power Plant."

5.5.5 ANSI N45.2.2 - 1978, "Packaging, Shipping, Receiving, Storage and Handling of Items for Nuclear Power Plants."

5.5.6 "Vertical Steam Generator Stress Report," April 20, 1969 by R.P. Wedler (Westinghouse).

5.5.7 RG&E Ginna Technical Supplement accompanying application to increase power.

5.5.8 RG&E Ginna Station procedure WC-15, Rev. 1, "Secondary Water Chemistry Monitoring," October 30, 1980.

5.5.9 RG&E Ginna Station Procedure WC-1, Rev. 4, "A List of Sample Chemical Parameters and Sampling Schedule," October 27, 1980.

5.6 Seismic Category

Seismic classification of the sleeves is in accordance with Regulatory Guide 1.29. The tube sleeves are a seismic Category I component. The seismic boundaries for the sleeves are the steam generator tubes and tubesheet. (See Section 8.0 for Analysis).

5.7 Quality Group

Quality classification of the sleeves is in accordance with Regulatory Guide 1.26. The sleeves are a quality Class I component. (See Section 8.0 for Analysis).

5.8 Code Class

The sleeves are considered Class I components as defined in ASME Code, Section III. (See Section 8.0 for Analysis).

5.9 Codes, Standards and Regulatory Requirements

The following requirements apply to the design and installation of the sleeves in the steam generator tubes.

5.9.1 The design and fabrication of the sleeves are consistent with the intent of the ASME B&PV Code Section III although strict compliance with the administrative procedures including Code Stamping and Third Party Inspection is not required.

5.9.2 Brazing and Welding procedures and processes for sleeve attachment are qualified in accordance with the ASME B&PV Code Sections IX and XI.

5.9.3 Materials for the structural members of the sleeves are in accordance with the ASME B&PV Code Section II. Non-structural sleeve materials shall be compatible with primary and secondary water chemistry.

5.9.4 Installation of sleeves is in accordance with the intent of the ASME B&PV Code Section XI.

5.10 Design Conditions

5.10.1 The sleeve design parameters are extracted from the steam generator design data given in Tables 5-1, 5-2, and 5-7.

5.10.2 Feedwater is heated to saturation temperature before entering the boiler section at the tubesheet.

5.11 Load Conditions

The following requirements shall apply to the design of the sleeves.

5.11.1 The sleeves are designed to the loading conditions stated herein and function as required by this specification as a result of these conditions. The loading conditions to be considered shall include: operating pressure, thermal stresses, flow induced vibration, seismic acceleration and displacements, and loss-of-coolant accident (LOCA). (See Section 8.0 for Analysis).

5.11.2 The operating pressures for the steam generator where the sleeves are installed for operating conditions at 100% are given in Table 5-4. (See Section 8.0 for Analysis).

5.11.3 The thermal and loading cycles are provided in Table 5-3. These values are used in determining the maximum metal temp-

erature, gradients and thermal loadings which will exist under the specified transients and conditions. (See Section 8.0 for Analysis).

5.11.4 Flow velocities of 8.1 ft/sec at the tube bundle periphery (feedwater inlet at the top of the tubesheet) decreasing to 2.0 ft/sec in the interior region of the tube bundle were used for the sleeved area of the steam generator. (See Section 8.0 for Analysis).

5.11.5 Vibration analysis for normal operation (including testing) were performed. The vibration analyses considered the structural and hydraulic system frequencies and associated mode shapes, and the random and deterministic excitation. (See Section 8.0 for Analysis).

5.11.6 An engineering evaluation to determine the effect of installed sleeves on plant safety during postulated seismic and LOCA events was performed. The original design seismic and LOCA loads of the steam generator were considered. (See Section 8.0 for Analysis).

5.11.7 The design and service load combinations are as specified in Table Table 5-5.

5.11.8 The stress limits as defined in ASME Section III were used for the load combinations specified in Table 5-5. (See Section 8.0 for Analysis).

5.12 Environmental Conditions

The sleeves are designed to withstand the environmental conditions expected in the inside of the steam generator. These conditions are given in Tables 5-2A, 5-2B, and 5-4.

5.13 Interface Requirements

The attachment of the sleeves to the steam generator tube is by means of explosive welding and brazing. The lower end of the sleeve is explosive welded to form a seal weld. The upper end is expanded against the tube I.D. and brazed. Distortion of the tubesheet ligament is minimized during the welding operation. (See Section 6.0 for Design).

5.14 Material Requirements

The sleeve material is compatible with the existing steam generator materials. The sleeve material was selected to optimize the mechanical design and maximize the resistance to intergranular attack. Brazing material is compatible with the primary and secondary system environment and is equal to or better than the original tube material for corrosion resistance. (See Section 6.0 for Design).

5.15 Mechanical Requirements

5.15.1 The sleeve design considered hydraulically induced vibrations. (See Section 8.0 for Analysis).

5.15.2 The sleeving design utilizes a thin walled, ID sleeve extending above the tubesheet. The length can be varied between approximately 24 and 42 inches depending on space available for access within the channel. The overall objective is to maximize the number of tubes accessible for sleeving. (See Section 6.0 for Design).

5.14 Structural Requirements

The installed sleeve does not reduce the margin of safety below acceptable levels.

5.17 Hydraulic Requirements

The sleeve is designed to minimize the effect on the hydraulic characteristics of the steam generator. The maximum primary side pressure drop, as given in Table 5-6 and Reference E.4, is 32.2 psi for the steam generator U-tubes (3,260 tube total). The sleeves are to be designed to the operating conditions at 100% load (Table 5-4) and to the reactor coolant pump design data and estimated performance characteristics (Table 5-7) (See Section 8.0 for Analysis).

5.18 Chemistry Requirements

The water chemistry requirements for the secondary side of the steam generator are given in Tables 5-2A and 5-2B. Table 5-2A provides the secondary side water chemistry specifications, and Table 5-2B provides the frequency of testing and the normal expected concentration ranges for full power operation for each chemical parameter for the secondary side. (See Section 6.0 for Design and 7.0 for Testing).

5.19 Electrical Requirements

Not Applicable

5.20 Operational Requirements

The sleeves are designed to withstand the operating conditions at 100% load as given in Table 5-4. (See Section 7.0 for Testing and 8.0 for Analysis).

5.21 Instrumentation and Control Requirements

Not Applicable

5.22 Access and Administrative Control Requirements

Not Applicable

5.23 Redundancy, Diversity and Separation Requirements

Not Applicable

5.24 Failure Effects Requirements

The sleeves are designed to remain in place (ie will not result in a loose part) during a seismic or LOCA event. (See Section 8.0 for Analysis)

5.25 Test Performed (See Section 7.0 for Testing)

1. Testing necessary for design verification.
2. Random sleeves were be leak tested during installation to verify that there is no leakage at the upper attachments.

5.26 Accessibility, Maintenance, Repair and Inservice Inspection Requirements (See Section 10.0 for Inspectability)

5.26.1 Access to the existing steam generator components for routine maintenance and inspection have not been adversely affected by installation of the test sleeves.

5.26.2 The sleeves are designed to permit the performance of all tests and inspections required by ASME Section XI for Class I components. Eddy current inspections can be used to allow simultaneous inspection of the test sleeve, tube and tubesheet.

5.27 Personnel Requirements

Not Applicable

5.28 Transportability Requirements

None

5.29 Fire Protection Requirements

Not Applicable

5.30 Handling Requirements

The sleeves have been shipped, handled and stored in accordance with the appropriate requirements of ANSI N45.2.2-1978.

5.31 Public Safety Requirements

None

5.32 Applicability

None

5.33 Personnel Safety Requirements

None

5.34 Unique Requirements

None

TABLE 5-1

STEAM GENERATOR DESIGN DATA

Design Pressure, Reactor Coolant/Steam, psig		2485/1085
Reactor Coolant Hydrostatic Test Pressure (tube side-cold), psig		3110
Design Temperature, Reactor Coolant/Steam, °F		650/556
Reactor Coolant Flow, lb/hr		34.0×10^6
Heat Transferred, Btu/hr		2218×10^6
Steam Conditions at Full Load, Outlet Nozzle:		
Steam Flow, lb/hr		3.13×10^6
Steam Temperature °F		513.8
Steam Pressure, psig		755
Feedwater Temperature, °F		427.3
Overall Height, ft-in.		63 - 1.63
Shell OD, upper/lower, in.		166/127.5
Heat Output	1520 MWt	Zero Power
Reactor Coolant Water Volume, ft^3	928	928
Primary Side Fluid Heat Content, Btu	24.99×10^6	24.42×10^6
Secondary Side Water Volume, ft^3	1681	2821
Secondary Side Steam Volume, ft^3	2898	1758
Secondary Side Fluid Heat Content, Btu	45.80×10^6	75.50×10^6

PROPRIETARY

Table 5-2A

SECONDARY CHEMISTRY SPECIFICATIONS

PARAMETER	NORMAL POWER OPERATION		LIMITED NORMAL POWER OPERATIONAL CONTROL CONDITIONS (1)	POWER OPERATION DURING STARTUP (2)	
	FEEDWATER	BLOWDOWN	BLOWDOWN	FEEDWATER	BLOWDOWN
pH @ 25°C*	8.8 - 9.2	8-5 - 9.0	<8.5 - >9.2	8.8 - 9.5	8.5 - 10.0
Cation Conductivity* uMHOS/cm @ 25°C	N/A	<2.0	2.0 - 7.0	N/A	<7.0
Sodium, PPM*	N/A	<0.10	0.10 - 0.50	N/A	<1.0
Chloride, PPM*	N/A	<0.15	0.15 - 0.50	N/A	<0.5
Silica, PPM	N/A	<1.0	N/A	N/A	<5.0
Dissolved Oxygen, PPB*	<5.0	N/A	N/A	<100	N/A
Ammonia, PPM	≤0.5	≤0.5	N/A	N/A	<10.0
Hydrazine, PPM	$(O_2)+\geq0.005$	N/A	N/A	$(O_2)+>0.005$	N/A
Free Hydroxide PPM As $CaCO_3$	N/A	<0.15	N/A	N/A	<0.15
Total Conductivity* uMHOS/cm @ 25°C	≤4.0	N/A	N/A	N/A	N/A
Iron, PPB	<10	N/A	N/A	<100	N/A
Copper, PPB	<5	N/A	N/A	<50	N/A
Suspended Solids, PPM	N/A	<1.0	N/A	N/A	N/A
Blowdown Rate GPM/SG	N/A	Continuous As Required	Continuous As Required	N/A	Maximum Available

* = In-line continuous Measurement Recommended

(1) If during normal operation (not coincident with startup), the indicated pH range or the range for either cation conductivity, sodium or chloride is exceeded, attempts will be made to correct those conditions as soon as practicable. The period of operation within these limits should not exceed one week. The period of allowable unit operation with confirmed cation conductivity, sodium or chloride concentration greater than the upper limitations should not exceed 24 hours.

(2) Specifications are listed as an example of potential impurity concentration upon startup. Until attaining full power levels, additional latitude is necessary because of the expected increased levels of contaminants.

PROPRIETARY

TABLE 5-2B
SECONDARY SIDE
CHEMICAL PARAMETERS AND CONCENTRATION RANGE

Parameter	Normal Range
A. STEAM GENERATOR	
Sodium[1]	5 - 30 ppb
pH[1]	8.5 - 9.0
Chloride[1]	< 50 ppb
Phosphate	< 0.05 ppm
Ammonia	0.10 - 0.30 ppm
Free Hydroxide	- .15 - + .05 ppm
Silica	< 50 ppb
Suspended Solids	< 1 ppm
Radioiodine	M.D.A.
Cation Conductivity[1]	0.2 - 1.0 umhos
Activity	MDA - 5×10^{-8} uCi/cc
Conductivity[1]	1.0 - 2.0 umhos
Tritium	M.D.A.
B. FEEDWATER	
pH[1]	8.8 - 9.2
Hydrazine	10 - 30 ppb
Cation Conductivity[1]	0.05 - 0.15 umhos
Iron	< 10 ppb
Copper	< 5 ppb
Dissolved Oxygen[1]	< 5 ppb
Chloride	< 50 ppb
Conductivity	1.5 - 2.5
C. CONDENSATE	
pH[1]	8.8 - 9.2
Ammonia	0.10 - 0.30 ppm
Cation Conductivity[1]	.06 - .15 umhos
Iron	< 10 ppb
Copper	< 5 ppb
Dissolved Oxygen[1]	< 5 ppb
Chloride	< .05 ppm
D. HOTWELL SECTIONS	
Cation Conductivity[1]	0.05 - 0.10 umhos
Chloride	< .05 ppm
Sodium Analyzer Cross Calibration	N/A

PROPRIETARY

TABLE 5-2B
(Continued)

Parameter	Normal Range
E. CONDENSATE STORAGE TANKS	
Sodium	< 1 ppb
Chloride	< .05 ppm
Dissolved Oxygen	< .5 ppm
Flouride	< .15 ppm
Conductivity	< 2 umhos
pH	6 - 9
Silica	< 20 ppb
F. MIXED BED OUTLET	
Sodium	< 1 ppb
Chloride	< .05 ppm
G. HEATER DRAIN TANK	--
Sodium	1 ppb
Chloride	.05 ppm
H. CONDENSATE POLISHER SYSTEM INFLUENT AND EFFLUENT	
Cation Conductivity	0.06 - 0.15 umhos
Sodium Analyser Cross Calibration	N/A
I. CONDENSATE POLISHER MIXED BED EFFLUENT (sample each bed that's in service)	
Suspended Solids (3L)	---
Silica	< 2 ppb
Chloride	< 50 ppb
Iron	< 10 ppb
Copper	< 5 ppb
Conductivity	.04 - 2.5 umhos
Ammonia	0 - .30 ppm
J. HOUSE HEATING BOILER	
pH	---
Conductivity	---
Activity	M.D.A.

PROPRIETARY

TABLE 5-3

THERMAL AND LOADING CYCLES

Transient	Number of Cycles
Heatup and cooldown	200
Loading and Unloading	14,500
Reactor trip	400
Loss of Load	80
Power blackout[1]	40
Loss of flow (reversed flow)	80
Loss of secondary pressure - return to power[2]	6
Loss of secondary pressure - no return to power[2]	6
Loss of primary coolant (feed flow)[3]	1
Loss of primary coolant (no feed flow)[3]	1
5% step - increase, decrease	2,000
10% step - increase, decrease	2,000
20% step - increase, decrease	2,000
40% step - decrease	200
50% step - decrease	200
95% step - decrease	80
Initial primary hydrotest	1
Subsequent primary hydrotest	50
Initial secondary hydrotest	1
Subsequent secondary hydrotest	50
Primary to secondary leak test	5
Secondary to primary leak test	5

Steady state fluctuations - The reactor coolant average temperature for purposes of design is assumed to increase and decrease a maximum of 6°F in one minute. The corresponding reactor coolant pressure variation is less than 100 psig. It is assumed that an infinite number of such fluctuations will recur.

Pressure Tests - Since these tests are very much the same, they will be tabulated.

Test	Number of Cycles	Primary Side Temp.	Primary Side Press.	Secondary Side Temp.	Secondary Side Press.
Initial Primary Hydrotest	1	70°F	3106 psi	70°F	0
Subsequent Primary Hydrotest	50	400°F	2485 psi	70°F	0
Initial Secondary Hydrotest	1	70°F	0	70°F	1356 psi
Subsequent Secondary Hydrotest	50	70°F	0	70°F	1085 psi
Primary to Secondary Leak Test	5	90°F	2250 psi	70°F	0
Secondary to Primary Leak Test	5	70°F	0	90°F	840 psi

PROPRIETARY

TABLE 5-3

THERMAL AND LOADING CYCLES

1. Power Blackout - The steam generator was designed to withstand the introduction of 70°F feedwater into the vessel while the reactor coolant system was at 650°F and with 10 feet of water above the tubesheet on the secondary side. The feedwater flow rate was 200 gpm. The maximum number of cycles was 40.

2. Loss of Secondary Pressure - Following the loss of secondary pressure, the primary to secondary boundary components shall withstand 2485 psi differential at 668°F without violating the primary to secondary boundary. The primary stresses during this occurrence shall be evaluated in accordance with Section III of the ASME Code where S_m is 0.9 times the minimum specified yield strength at 668°F.

3. Loss of Primary Coolant - Following a loss of primary coolant, it was assumed that the steam generator primary side was filled instantaneously with 70°F water to a pressure of 50 psig. On the shell side two conditions could exist. If feedwater flow was maintained, the shell side fluid temperature was gradually decreased to 70°F. If feedwater flow were stopped, the secondary temperature would increase to 545°F. The shell side pressure was held constant at 1100 psia. For conservatism both secondary side cases were assumed to occur once.

PROPRIETARY

TABLE 5-4

OPERATING CONDITIONS AT 100% LOAD

Primary Side Flow Rate/SG	34.0×10^6 lb/hr.
Primary Side Inlet Temperature	601.5° F.
Primary Side Outlet Temperature	551.9° F.
Primary Side Pressure	2235 psig
Heat Transferred/SG	2218×10^6 Btu/hr.
Feedwater Flow Rate/SG	2.75×10^6 lb./hr.
Feedwater Temperature	415.1° F.
Steam Flow Rate/SG	2.75×10^6 lb./hr.
Steam Temperature	517.7° F.
Steam Pressure	781.8 psig
Steam Quality	99.75% minimum
Total Heat Output	1520 MWt

PROPRIETARY

TABLE 5-5

LOADING COMBINATIONS

Loading Case	Static	Transients	Seismic and LOCA
Design		PD	
Level A/B	DW	PO and ML and TL (Consideration of all specified Level A/B transient loading combinations)	OBE
Level D	DW	PO and HL	SSE and LOCA

PD - Design Pressure
DW - Dead Weight
ML - Mechanical Loads
HL - Hydraulic Loads
PO - Operating Pressure

SSE - Safe Shutdown Earthquake
OBE - Operating Basis Earthquake

TABLE 5-6

REACTOR COOLANT SYSTEM DESIGN PRESSURE DROP

	Pressure Drop, psi
Across Pump Discharge Leg	1.3
Across Vessel, including nozzles	44.0
Across Hot Leg	1.5
Across Steam Generator	32.2
Across Pump Suction Leg	3.0
Total Pressure Drop	82.0

PROPRIETARY

TABLE 5-7

REACTOR COOLANT PUMPS DESIGN DATA

Number of Pumps	2
Design Pressure/Operating Pressure, psig	2485/2235
Hydrostatic Test Pressure (cold), psig	3110
Design Temperature (casing), °F	650
RPM at Nameplate Rating	1189
Suction Temperature, °F	556
Developed Head, ft.	252
Net Positive Suction Head, ft.	170
Capacity, gpm	90,000
Seal Water Injection, gpm	8
Seal Water Injection, gpm	3
Pump Discharge Nozzle ID, in.	27-1/2
Pump Suction Nozzle ID, in.	31
Overall Unit Height, ft.	28.22
Water Volume, $ft.^3$	192
Pump-Motor Moment of Inertia, $lb\text{-}ft.^2$	80,000
Motor Data:	
Type	AC Induction Single Speed
Voltage	4000
Phase	3
Frequency, cps	60
Starting	
Input (hot reactor coolant), kw	4000
Input (cold reactor coolant), kw	5300
Power, HP (Nameplate)	6000

PROPRIETARY

6.0 SLEEVING DESIGN

The objective of sleeving is to keep steam generator tubes with pluggable indication in service by providing a new pressure boundary which spans the defective area. The sleeving process integrates many separate areas that include:

- Sleeve Design Materials of construction were selected; the sleeve size and geometry were established. The design was qualified through a combination of engineering analyses, strength testing, and corrosion testing.
- Sleeve/Tube Attachment Design The methods to attach the sleeve to the tubing were developed. The design was qualified by fatigue testing, testing the ultimate strength, hydrostatic pressure testing, and corrosion testing.
- Qualifying the Sleeve Installation Process The process for installing the sleeve in the field was developed. Since the installation process and the design of the sleeve/tube attachment proceeded in parallel, the design qualification of the attachment also qualified the installation process.
- In-Service Inspection of Tubes/Sleeves An eddy current technique to inspect the sleeve and the tubing was developed and qualified to meet the requirements of the ASME Code Section XI.
- Installation Tooling - Tooling to install the sleeves and control the process was designed, manufactured, and proven through mock-up testing.

There are five basic installation steps for a single sleeve.

1. The tube is cleaned in the region where the braze will be made. The area of the explosive weld is also lightly cleaned at this time.

2. A sleeve is inserted into the tube and explosively expanded in the "braze" region.

3. A heater is inserted into the sleeve. The sleeve is brazed and the heater is then removed.

4. An explosive cartridge is inserted into the lower end of the sleeve to explosively weld the sleeve to the tube.

5. The sleeve is nondestructively examined using eddy-current inspection.

Each of these steps requires specific equipment. The components, i.e., the sleeve, the explosive expander, and the explosive weld device, are discussed in this section. The installation tooling is described in Section 9.0 identifies the tooling utilized. The eddy current in- spection is discussed in Section 10.0.

6.1 Sleeve Design

6.1.1 General

The bimetallic sleeve is a 36-inch long, thin wall, composite alloy sleeve (Figure 6.5). The composite sleeve consists of an Inconel 600 core bonded to an a layer of Nickel 200. The composite is extruded at a high temperature to produce the bimetallic, diffusion-bonded sleeve (Figures 6-3 and 6-4).

The nickel and Inconel in the sleeve design conforms to the chemical composition requirements given in SB-163 of the ASME Code. The bimetallic sleeve is certified to the ASME Code and is a Class I pressure boundary material.

After hot extrusion, the bimetallic sleeve is finished to nominal outside and inside diameters of 0.745 inches and 0.634 inches, respectively. The nickel layer is approximately 0.004 inches thick.

6.1.2 Sleeve Upper End

The upper end of the bimetallic sleeve is designed to be expanded into the steam generator tube and attached to the tube by brazing. The braze joint design consists of two, 1/4 inch wide pre-brazed rings, spaced 1/4 inch apart. The upper edge of the upper ring is one inch from the top of the sleeve. The grooves on the sleeve are pre-brazed with BAu-4 filler metal using a vacuum furnace.

6.1.3 Sleeve Lower End

The lower end of the bimetallic sleeve is designed to be explosively welded to the steam generator tube. The explosive welding process involves detonating an explosive cartridge placed 2-1/2 inches inside the sleeve. With detonation of the charge the sleeve is welded to the tube over a one-inch length. The explosive welding process also expands the sleeve so that it touches the tube for a length of 1/2 inch above and below the one-inch welded region.

6.1.4 Sleeve Fabrication

The bimetallic sleeves are fabricated from a tubular product comprising an outer nickel layer bonded to an Inconel core (Alloy 600). The product is manufactured by high-temperature extrusion followed by cold finishing to achieve final dimensions.

The tubular composite of Inconel and nickel is cut into 48-inch lengths. These lengths are then cut to 36- and 12- inch lengths. The 12-inch lengths are used as tension test specimens.

The 36-inch sleeves are machined to an internal diameter of 0.636 $\pm$ 0.001 inches. The braze grooves are machined into the OD of the upper end of the sleeve, and the braze collar is match machined with the grooves. The braze collar ID is approximately 0.001 inches smaller than the OD of the sleeve.

The BAu-4 braze material is cut into lengths of 2.281 $\pm$ 0.016 inches and wrapped around the sleeves in the braze grooves. The braze collar is shrink-fitted over the braze grooves on the sleeve. The sleeve, with the collar in place, is heated in a vacuum furnace to 1800°F $\pm$ 20°F until the BAu-4 is brazed to the grooves in the sleeve. This process requires 3 to 30 minutes, depending on furnace load. After brazing the sleeve is cooled and the collar is machined off.

Following the installation of the braze material, the sleeves are heat treated to enhance its ability to withstand IGA. This heat treatment consists of holding the sleeve at 1325°F $\pm$ 50°F for 15 hours

Testing was conducted in the braze, weld, and mid-span regions of the sleeve, to evaluate the effect of the heat treatements on the mechanical properties of the sleeve. These tests consisted of processing test sleeves with the nickel outer layer removed through pre-braze, expansion, and braze cycles and pulling tension tests on both expanded and non-expanded areas. The testing illustrated the expansion process for the explosive expansion (braze area) and explosive weld induced some "work-hardening" that actually enhanced the mechanical properties relative to the as-fabricated values. The testing also showed that mid-span mechanical properties have been reduced due to the pre-braze operation. This pre-braze operation (if conducted two or three times) will still maintain the ASME Code minimum yield strength value of 35,000 psi.

6.2 Explosive Expansion Cartridge Assembly

One portion of the B&W rapid sleeving program involves expanding the upper (pre-brazed) end of the sleeve to contact the adjacent inner surface of the steam generator tube. This is accomplished with the explosive expansion device briefly described below, (see Figure 6-1):

The extension arm (1) is a stainless steel unit that is an intermediary piece between the tooling and the explosive area. It allows the expansion device to be positioned inside the sleeve. The stainless steel bottom cap (2) is connected to the extension arm. This cap provides support on one end for the polyurethane expansion sleeve (4). The stainless steel top cap (3) holds the other end of the expansion sleeve in place. Giving the explosive area support is the stainless steel central dowel (5). The dowel is threaded at each end and is joined to both the bottom and top caps. The dowel fits inside the expansion sleeve. The annulus between the expansion sleeve and the central dowel is where the propellant is placed. Ignition wires (leading through the extension arm to a control panel) are in contact with the propellant.

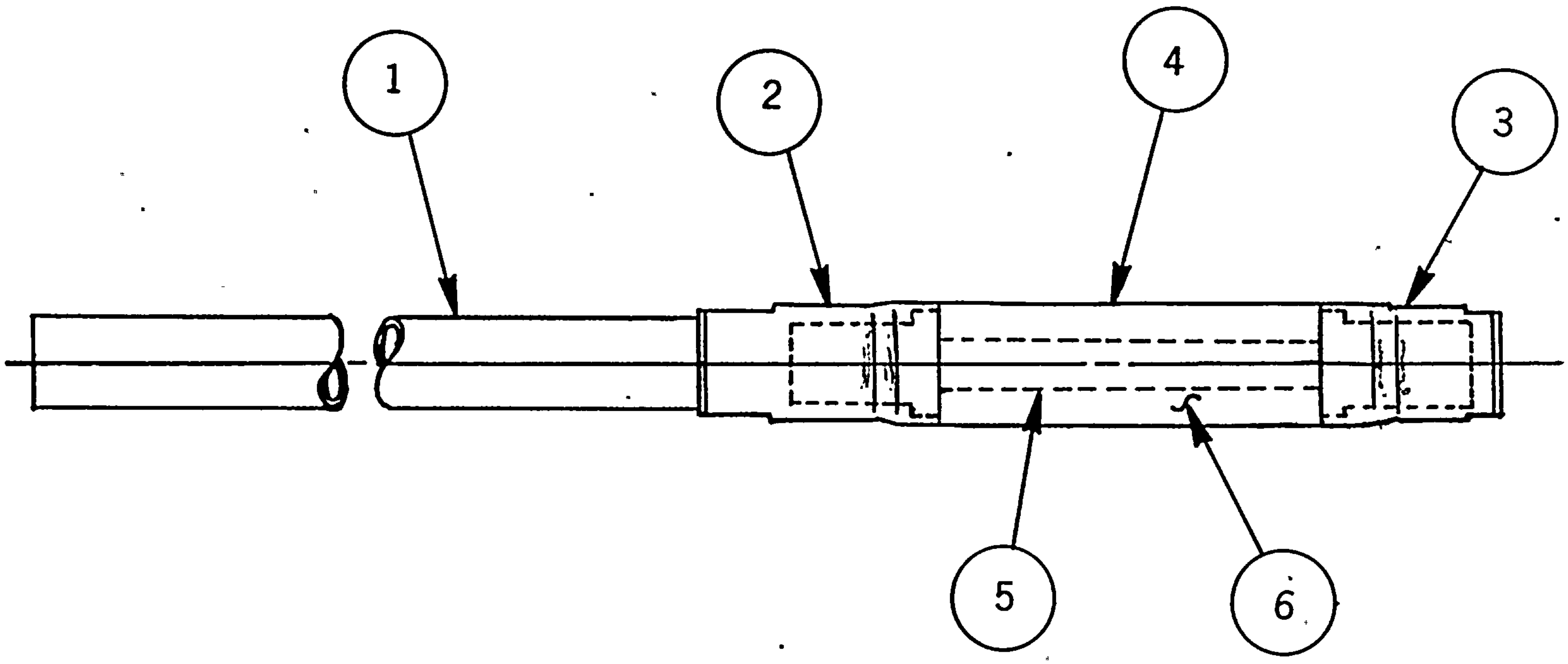
The expansion device assembly is inserted into the repair sleeve by remote tooling so that the expansion sleeve is at the same elevation as the pre-brazed (or dual braze ring) area. The reusable device is fired and then removed and cleaned and inspected before it is used again.

6.3 Explosive Welding Cartridge

The explosive welding cartridge (Figure 6-2) is used to make the weld that seals the bottom end of the sleeve to the steam generator tube.

The cup (2) is fabricated of plastic bar stock. In the assembled cartridge, it contains the explosive material. The plug (3) provides a housing for the detonator and with its integral "spring clips," provides a way to keep the catridge assembly inserted in the sleeve after the tooling is removed. The detonator (4) ignites the explosive material while the explosive material (5) provides the force sufficient to weld the sleeve and tube together. Finally, the leadwire is connected to the detonator and provides a means of remotely firing the cartridge. Before the explosive welding cartridge is assembled, the detonator is bonded to the plug, and the explosive materials are placed in the cup. The cartridge is completed by gluing the plug and cup together. Charge/mass ratio of the explosives is important and carefully controlled. The assembled welding cartridge is inserted into the sleeve by remote tooling, then held in place by the plug clips (3), and fired.

Explosive Expansion Device Assembly



Scale: Full

FIGURE 6–1

PROPRIETARY

Explosive Welding Cartridge Assembly

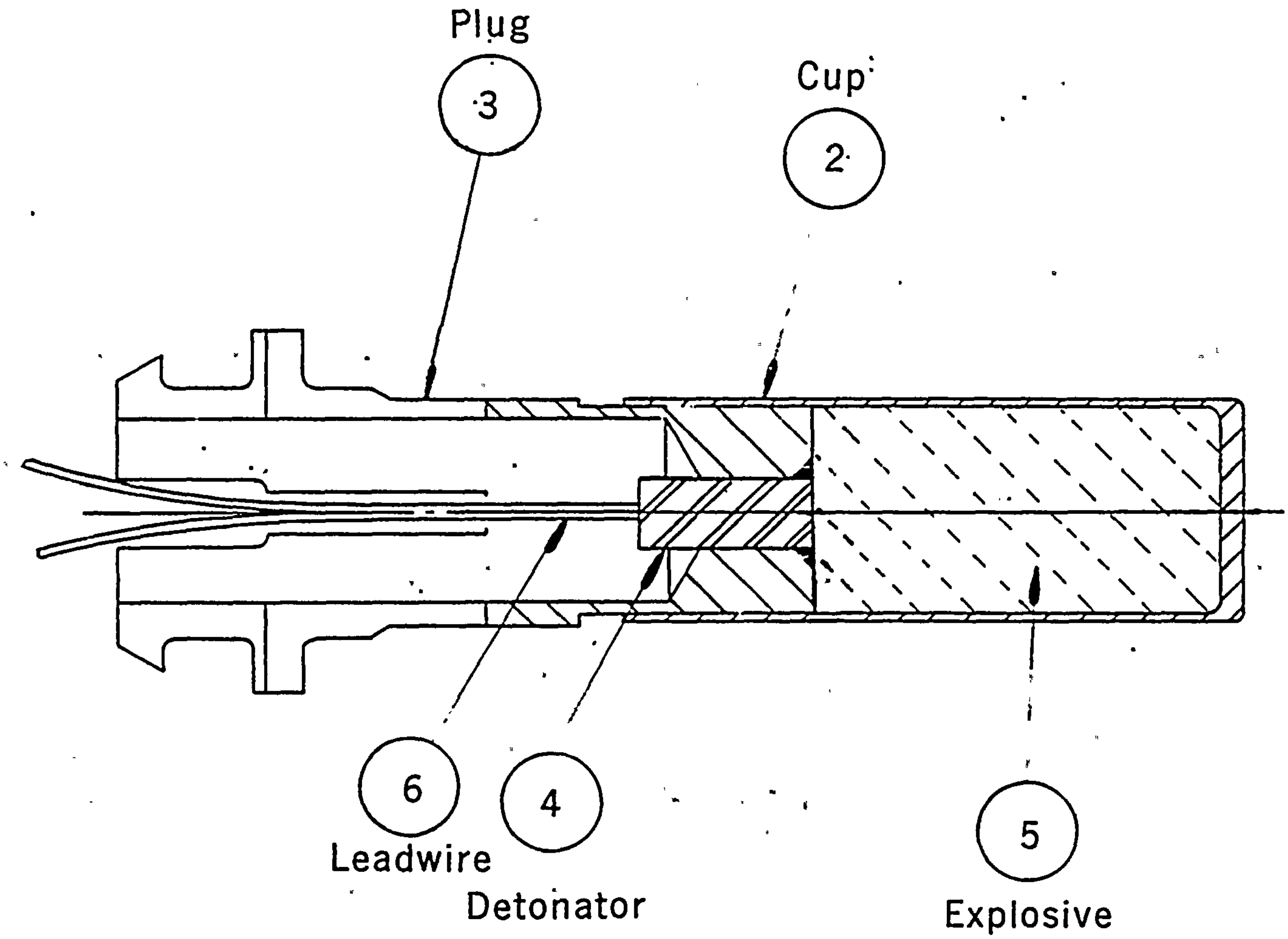


FIGURE 6–2

PROPRIETARY

Bimetallic Sleeve/Tube Explosive Weld

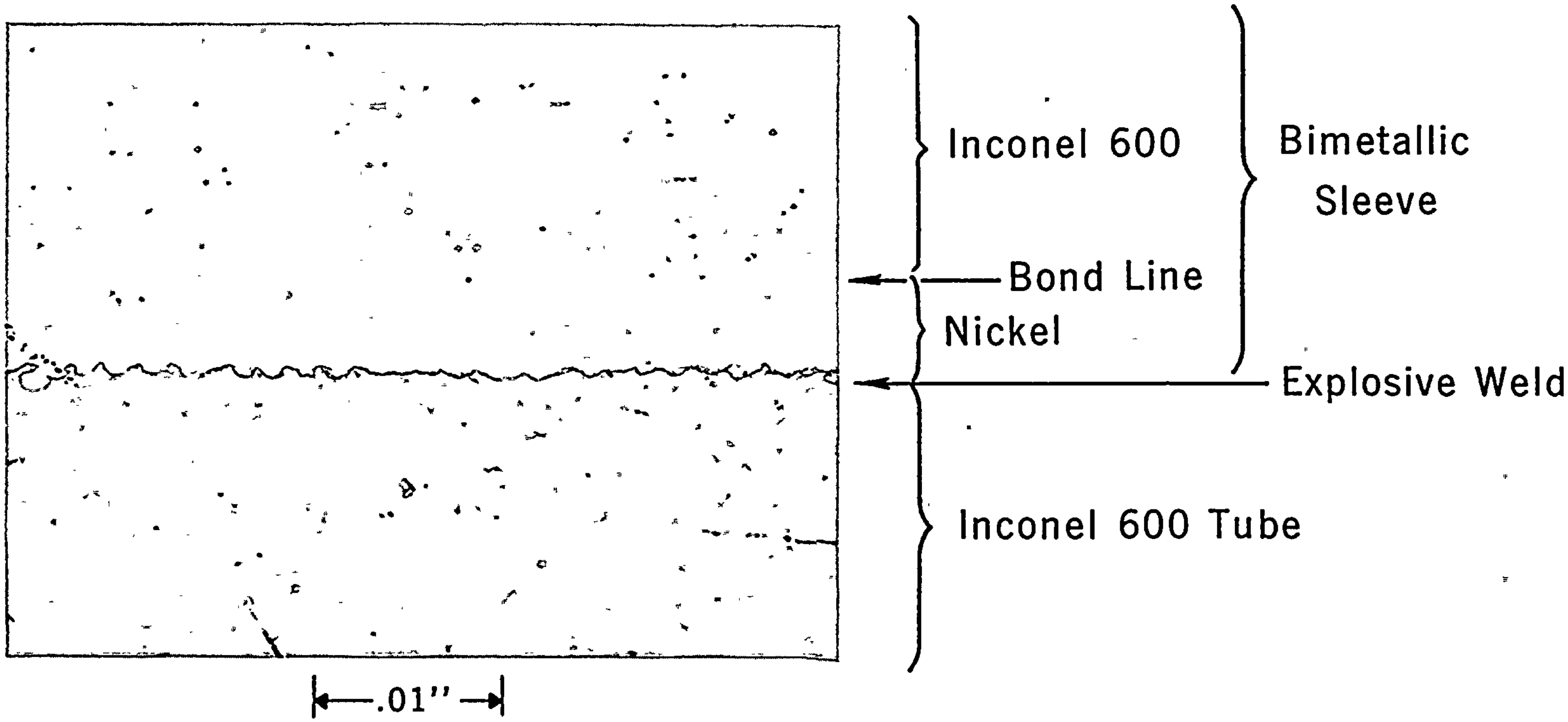
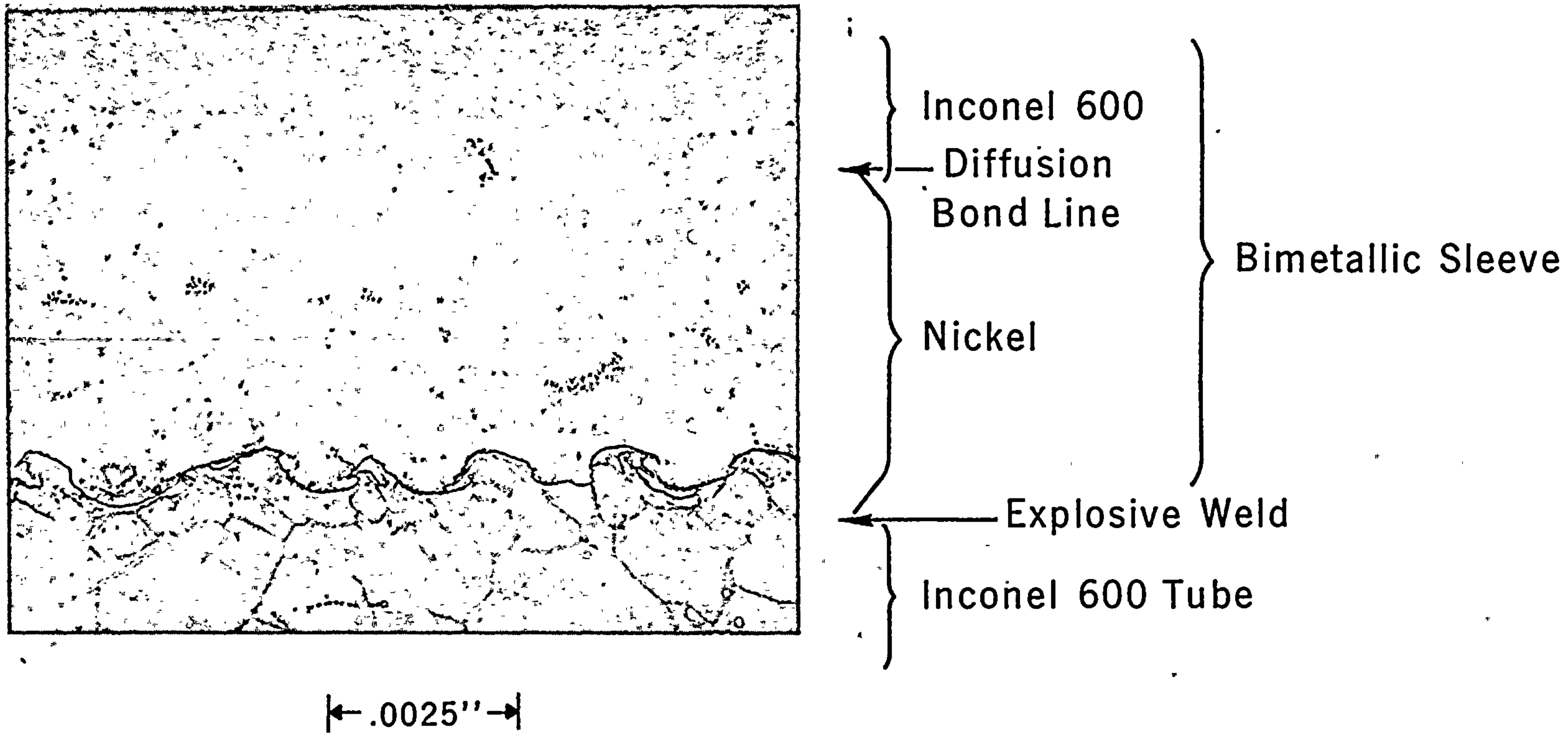


FIGURE 6–3

PROPRIETARY

Bimetallic Sleeve/Tube Explosive Weld

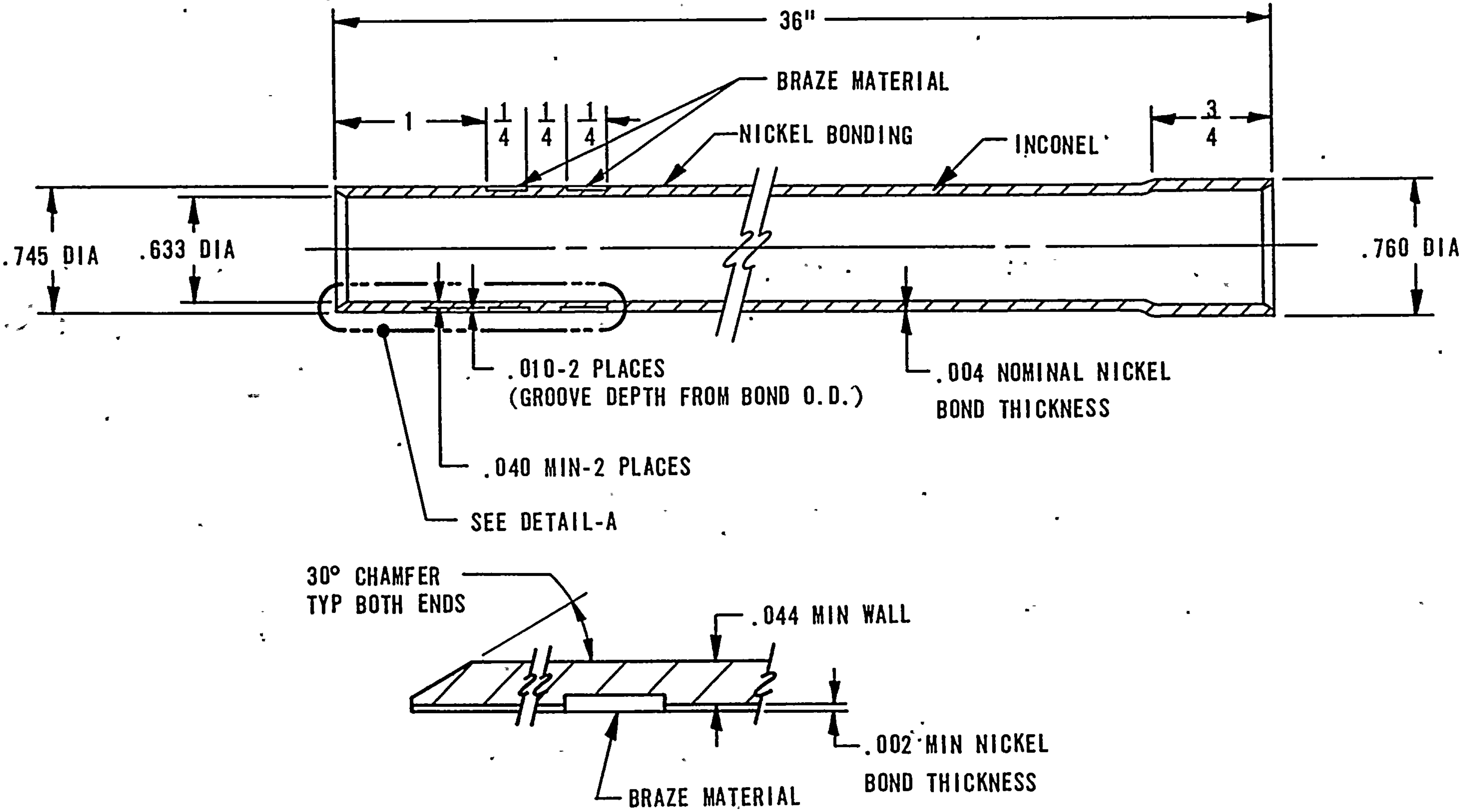


Higher Magnification View Of Previous Photo

FIGURE 6–4

PROPRIETARY

Figure 6-5 CO-EXTRUDED BIMETALLIC SLEEVE DESIGN



DETAIL-A

PROPRIETARY

7.0 TESTING

7.1 Introduction

This section discusses the various test programs which have been conducted during the development and design verification of the B&W sealable sleeve. The purpose of testing is to verify that:

1) the overall process produces an acceptable product,
2) certain design features are acceptable for use in the steam generator environment, and
3) any process improvements do not compromise the design basis of the sleeve.

The test programs have supported three progressive phases of development for the installation of sleeves at the Ginna plant. The initial phase consisted of installing five test sleeves during November 1980. This phase showed that sealable sleeves could in fact be installed. The second phase involved improvements to tooling to speed up the process and lower radiation exposure. This phase culminated with the installation of 16 additional test sleeves in April 1981 with a significant exposure reduction. The most recent phase of development has been in support of preventative sleeving of approximately sixteen hundred (1600) tubes in each generator using significant sleeve process advancements. This phase has been termed "rapid sleeving" development.

This section of the report deals with the test programs that supported the Rapid Sleeving Process Improvement and Process Qualification. The Process Improvement discussion addresses those changes made to the process since April 1981. The Process Qualification discussion touches on all aspects of verification testing since the sleeving program began in 1980.

7.2 Process Development - Design Considerations

The process development for the sealable sleeve was based on known information and requirements for the Ginna steam generators. The steam generator tube straightness, tube size, and tube mechanical properties were controlled by the tube mill fabricator and have been verified by tube pull information. The sleeve process is intended to bridge the degraded steam generator tube area. The sleeve braze is to be applied over a non-flawed area. Tube irregularities are expected and process verification has considered tube ovality to .010 inches, tube and sleeve as fabricated yield strength variances, tube wall thickness variances, and clearance variances between sleeves and tubes. These variances have been considered in the process and have been found to be of no particular concern relative to the quality and reliability of the sleeve system process itself. The critical parameters to be considered in the test program are as follows:

Variables	Control Mechanism
Steam Generator Tube	
I.D. Size	Customer Specification
Straightness	Profilometry
Mechanical Properties	Customer Spec/Tube Pull
Leaking Tubes	Eddy Current Testing.
Sealable Sleeve	
I.D. Size	Specification
Straightness	Specification
O.D. and Wall	Specification
Materials - Chem; Mech	Specification
Prebraze Region Discontinuities	Specification
Braze Point Design	Specification & P.Q.
Manufacturing	Procurement & Mfg. Proc.

Variables	Control Mechanism
Steam Generator Tube Cleaning	
Oxide Removal	Installation Procedure
Surface Roughness	Installation Procedure
Expansion	
Amount	Tooling Fab. Procedure & Sleeve Mfg. Proc.
Presence	Confirmation of Firing
Explosive Weld	
Presence	Confirmation of Detonation
Length of Weld	Exp. Cart. Fab. Proc.
Quality	Design Verification Tests & P.Q.
Cleanliness	Procedure
Debris	Tool Design & Cartridge Fab.
Brazing	
Cleanliness	Installation Proc.
Atmosphere	Procedure
Coil Location	Tooling & Sleeve Mfg.
Temp. Profile	Coil Design, Coil Location, Tooling
Temperature	Measured on Sleeve I.D.
Annulus	Expansion Devise Fab., Sleeve Fab.
Materials	Specification
Overheating	Proc. System Checkout
Underheating	Proc. System Checkout
Seal	Random Pneumatic Test
Equipment Usage Limit	Procedure
Rates	Procedure
Status of Brazing Operation	Procedure
Number of Braze Thermal Cycles	Procedure

Other considerations that influenced the development were:

1. The explosive weld is located to minimize its interaction upon the explosively applied cladding on the tubesheet.
2. The tube roll length has been considered in the sleeving system design. We do not alter the roll area.
3. The sludge depth is below the braze location.

With an understanding of the system considerations, variables and their associated control mechanism, the materials were selected. These were Inconel 600 as the base sleeve material because it is compatible with the primary system, and Nickel 200 as an outer layer to the Inconel because it has shown good resistance to caustic attack in corrosion testing. The braze material BAu-4 was selected for corrosion resistance, availability of the braze material, brazability characteristics, material melt point, and it is an ASME material. It is also desirable to have a braze material that can be applied in an inert atmosphere as opposed to a flux. This is due to the control problems associated with utilizing flux, and flux incompatibility with the primary system.

7.2.1 Cleaning Development

The level of cleanliness for the tube was dictated by the braze material selection. The BAu-4 on Inconel 600 requires a surface relatively free of an oxide coating to braze properly. In order to develop a cleaning process that was adaptable to a remote installation system, the tubing to be cleaned was first furnace oxidized and then cleaned by the candidate cleaning method. After a visual inspection for cleanliness, a braze flow test was conducted to verify brazeability.

Cleaning by honing was selected for its adaptability to remote tooling. A variety of hone materials were tested, i.e., silicon carbide, boron carbide, and aluminum oxide, as well as a variety of grit sizes (medium, fine, and very fine). Also, the hone diameter, the stroke speed, and RPM were varied. The final results established the hone material, grit size, drive motor horsepower and cable size for the remote tooling.

The results of additional cleaning tests provided the basis for increasing installation speed of rapid sleeving by illustrating that complete moisture removal prior to brazing is not essential. This eliminated the requirement to dry the tube completely before brazing. Once the hone was selected, tests were performed to determine the number of swabs to be used until the tube was clean enough to braze. Both moist and dry swabs were tested along with a variety of moist and dry swab combinations. The final cleaning process as qualified has three acceptable methods of cleaning: 1) a single hone pass with two swab passes, 2) a hone-swab combination, and 3) a hone-swab combination with a short swab. Cleaning method number 3 a hone-swab combination with a short swab will be utilized for sleeve installation at Ginna.

The explosive weld region is less sensitive to oxidation than is the braze region and therefore requires less cleaning.

The final cleaning process was verified on an actual Ginna tube, and the furnace oxide was found harder to remove than was the oxide on the actual tube. The cleaning system and methodology were therefore considered conservative.

7.2.2 Explosive Expansion Development

The first two sleeving operations at RG&E in 1980 and 1981 were performed utilizing hydraulic expansion. Hydraulic expansion is much slower than explosive expansion; therefore a time savings could be realized by developing an explosive expansion technique.

The explosive expansion process must be reliable, must be capable of creating the proper annulus between the sleeve and tube, and must present no harmful materials to the primary system. The explosive expander described in Section 6.0 accomplishes these goals.

A number of tests were performed to establish the charge size required for maintaining a proper annulus and tube expansion. Charge size variance was considered along with variances in sleeve and tube material strengths, wall thicknesses, clearance between tube and sleeve, and tube ovality. These tests and the associated tension (pull out) tests identified a tube expansion of 7 mils as the nominal tube expansion with a standard deviation of 2 mils. This yields a 95% confidence level that the minimum 3 mil tube expansion will be achieved on each expansion.

Finally, as a second check, the explosive expansion pressure was compared to the hydraulic expansion force and found to be almost identical for the same tube expansion.

7.2.3 Braze Development

The braze material requires a relatively clean, oxide-free environment to assure a good braze. A clean braze environment can be maintained through several heating methods, i.e., resistance cartridge, oxy-fuel mixture, chemical heating, and induction heating. Induction heating with a gas purge was decided upon based on environment for brazing. Purge gas tests were conducted to optimize the gas flow to assure a minimal purge time yet not force the braze material out of the annulus. After a number of braze purge gas tests, a flow rate of 50 SCF per hour was established for tube purge. This yields five volume replacements in a tube in the required five minute purge period. The gas flow rate is then dropped to 20 SCF per hour for the actual braze process.

The braze coil design was verified by testing. These tests utilized the existing information about the braze reservoirs in the sleeve (i.e., the groove depths and width and the known annulus clearance) to verify the braze quantity requirements and identify the mechanical properties of the expansion area following braze. The objective of the braze coil tests was to control the temperature so that the braze material melted and flowed without the temperature getting high enough to anneal the tube. Tests were conducted to establish the thermal profile in the sleeve utilizing thermocouples and metallographic examination of the braze assemblies. From these tests the braze coil design was fixed. The braze coil heats the braze region to 1830°F for two minutes; then a heat treat of five minutes is conducted on the braze area at a temperature of 1525°F. This heat treat is to provide a good grain boundary structure to resist corrosion. Corrosion tests were conducted on the braze region to assure that resistance to corrosive attack is maintained following the braze operation.

The temperature of the wand is controlled by an optical eye feedback system which monitors the sleeve temperature. The system when calibrated will assure that proper braze and heat treat temperatures are maintained.

The braze process to be utilitzed at Ginna was qualified by procedure to ensure consistency in the field.

7.2.4 Explosive Weld Development

The explosive weld development tests were performed to assure a proper weld could be accomplished using materials compatible with the steam generator. These qualification tests established the design of the explosive weld device. The weld itself is qualified in accordance with the intent of the ASME Boiler and Pressure Vessel Code Section XI, Paragraph IWB-4453.

The entire development process was aimed at providing material and a sleeving method that would maintain steam generator integrity and assure chemical and environmental compatiblity with the primary fluid. The process steps were selected to minimize the total radiation exposure during sleeve installation.

7.3 Process Qualification

The purpose of the Process Qualification testing is to verify that the overall installation process produces an acceptable sealable sleeve. The testing also addresses certain design features of the sleeve to show acceptability for use in a steam generator environment. The following discussion summarizes the various test programs to support the sleeve Process Qualification. All testing was performed under the control of the Alliance Research Center's Quality Assurance Program.

7.3.1 Design Verification Testing

7.3.1.1 Introduction

For this phase, mechanical tests were performed on specimens which simulate a bimetallic sealable sleeve installed within a steam generator tube in the tubesheet region of the Ginna steam generators. The specimens represent the materials and configuration of the sleeved region of the steam generator, and were assembled using tooling and procedures developed for the rapid sleeving program. Five such specimens were each subjected to a sequence of six tests for the purpose of demonstrating:

1) the mechanical integrity of the sleeve design and the integrity of the upper and lower sleeve-to-tube attachment joints,
2) the capability of the upper joint braze and lower joint weld to serve as the primary-to-secondary pressure boundary, and
3) the adequacy of the rapid sleeve installation process.

7.3.1.2 Specimen Design

Five specimens, each simulating the complete installation of a bimetallic sleeve in a Ginna steam generator, were fabricated and subjected to a sequence of hydrostatic, fatigue, and tension tests. The test specimen design, illustrated in Figure 7-1, essentially consists of a section of steam generator tube which is appropriately roller-expanded into a single-hole tubesheet mock-up and a bimetallic sleeve installed in the tube where the upper and lower

sleeve-to-tube joints are formed by the rapid sleeving processes. The degree of explosive expansion created at the upper end attachment joint prior to brazing is the same as that for an actual steam generator sleeve installation. To achieve a practical overall specimen length, a 12-inch long sleeve was employed which is one-third the length of the full-sized steam generator installation sleeves. Ten inches from the "B"-designated end of the steam generator tube are four 1/4-inch diameter holes through the tube wall, 90 degrees apart around the circumference. These holes simulate tube violations, exposing the annulus between the tube and installed sleeve. As such, they provide a means of pressurizing the specimen and detecting leakage, if any, during the hydrotests. The steam generator tube extends beyond the bottom face of the tubesheet mockup by several inches--unlike the actual steam generator geometry--to facilitate the design of a specimen-gripping system for the imposed tests. End plugs are brazed into the ends of the tube to serve as a means of gripping the specimen during fatigue testing and also to act as pressure boundary seals for the hydrotests. Each of the specimen components are described in the following subsections.

7.3.1.2.1 Steam Generator Tube

The steam generator tube section (26 inches long) was cut from lengths of Inconel 600 nuclear grade tubing. This material complies with the ASME Section II Code requirements, and is of the same size as the Ginna steam generator tubes. The nominal outside and inside diameters are 0.875 and 0.775 inch, respectively (0.050 inch wall thickness).

7.3.1.2.2 Bimetallic Sub-Sized Sleeve

The specimen sleeve design is identical to that of the installation sleeves in all respects with the exception that the overall length is 12 inches, one-third the length of the installation sleeves. The sleeves are fabricated from bimetallic tubing which consists of an Inconel 600 outer diameter surface. Nominal outside and inside diameters of the sleeve tubing are 0.745 and 0.635 inch, respectively. The 0.055 inch wall thickness is comprised of 0.050 inch Inconel and 0.005 inch nickel, nominally. Near the upper designated end of the sleeve, BAu-4 gold braze material is contained within the tube wall over a 3/4-inch long region of the tube. Through a 1800/1325F prebraze and heat-treat process, the braze material is deposited into two 1/4-inch wide circumferential grooves to a depth of 0.010 inch below the outer diameter surface. The two 360-degree circumferential braze bands are 1/4-inch apart.

7.3.1.2.3 Tubesheet Mock-Up

The single-hole tubeheet mockup represented the actual 22-inch thick steam generator tubesheet in that it served to back up and reinforce the explosive welding operation at the lower sleeve-to-tube joint. The mockup was a carbon steel cylinder, 4 inches long, with nominal outside and inside diameters of 2 inches and 0.890 inch, respectively (See Figure 7-2).

7.3.1.2.4 Tube End Plugs

The end plugs provided a means of gripping the specimen during the fatigue tests and served to isolate the primary from secondary side pressures during the hydrotests. They were machined from 304 stainless steel and were dimensionally compatible with the fatigue testing machine grips. The plugs were positioned within the ends of the tube, aligned with the specimen axis, and brazed to the inside diameter surface areas along the insertion depth (See Figure 7-3).

7.3.1.3 Specimen Assembly

The specimens were fabricated by employing the same procedures, processes, and tooling applicable to the installation of the full-sized bimetallic sleeves in the Ginna steam generators. This procedure covered cleaning, explosive expansion at the upper sleeve-to-tube joint, brazing the upper joint, and explosive welding of the lower sleeve-to-tube joint.

7.3.1.4 Verification Testing

Each of the five specimens (see Figure 7-4) were subjected to a sequence of six mechanical tests. The procedures for these tests, along with descriptions of the test facilities and instrumentation, are outlined below in the order in which the tests were performed.

7.3.1.4.1 Primary Side Hydrotest

Primary side hydrotesting involved internally pressurizing each specimen at room temperature, using a hand pump with water as the pressurizing medium. Through the hole in the upper end plug, the specimen was filled with water, connected to the pressurization plumbing, and slightly pressurized to bleed air from the total system prior to testing. The test was performed in a laboratory environment such that the secondary side of the specimen was at ambient (0 psig, room temperature) conditions. The specimen was pressurized slowly to approximately 3110 psig. When this test pressure was attained, the specimen was isolated from the hand pump by closing a valve in the pressurization system. The specimen remained under the imposed hydrostatic internal pressure loading for at least 10 minutes. During the pressure-hold period, the annulus between the tube and sleeve was observed through the four 1/4-inch diameter holes in the tube to assure that no leakage occurred from the primary-to-secondary side. Likewise, a bourdon tube pressure gauge connected to the specimen was monitored to assure that there was no primary side pressure loss during the hold period. At the end of the pressure-hold period, a bleed valve was opened to release the specimen pressure. Specimen internal pressure and time at pressure was recorded during the primary side hydrotest.

7.7.1.4.2 Secondary Side Hydrotest

Secondary side hydrotesting involved externally pressurizing each specimen at room temperature, using a hand pump with water as the pressurizing medium. The specimen was placed within a sealed, water-filled pressure vessel in a manner so as to impose external pressure loading onto the specimen while pressurizing the vessel. The inside of the specimen was also filled with water but vented to the laboratory environment outside the vessel through a tube enabling the primary side of the specimen to remain at ambient (0 psig, room temperature) conditions during testing. The vent tube was threaded into the hole in the upper end plug and extended through a sealed penetration in the top of the vessel. After installing the specimen and prior to testing, the vessel was slightly pressurized to bleed air from the total system. During testing, the vessel was slowly pressurized to approximately 1360 psig. When this test pressure was attained, the vessel was isolated from the hand pump by closing a valve in the pressurization system. The specimen remained under the imposed hydrostatic external pressure loading for at least 10 minutes. During the pressure-hold period, the open end of the vent tube was observed to assure that no leakage occurred from the secondary-to-primary side of the specimen. Likewise, a bourdon tube pressure gauge connected to the vessel was monitored to assure that there was no secondary side pressure loss during the hold period. At the end of the pressure-hold period, a bleed valve was opened to release the vessel pressure. Vessel pressure (specimen external pressure) and time at pressure were recorded.

7.3.1.4.3 Axial Fatigue Test

The specimens were fatigue tested using a 200,000-pound capacity MTS electro-hydraulic loading frame. Each RY specimen was subjected to combined axial tensile cyclic loading and constant internal (primary side) pressure, at 600F. The cyclic loading was applied in three successive stages for a total of 21,700 load cycles. During each stage, the load fluctuated sinusoidally between zero load and a peak tensile load. The internal pressure, peak tensile load, loading frequency, and number of loading cycles for the three stages of the fatigue test as prescribed were as follows (See Section 8.0 for load development):

	Internal Pressure (psig)	Peak Load (lbs)	Loading Frequency (cps)	Load Cycles
Stage A	1,710	3,035	1	200
Stage B	1,550	1,460	3	6,500
Stage C	1,550	1,340	3	15,000
Total Load Cycles				21,700

Before installing the specimen into the MTS frame for testing, it was slightly modified by cutting the steam generator tube 360 degrees around the circumference, through the four 1/4-inch diameter holes. This cut completely severed the tube so that the fatigue loads was carried entirely by the sleeve and sleeve-to-tube joints. After modifying the specimen, it was installed in the MTS frame by securing the upper "A" end plug within the upper grip. During the test, the specimen internal (primary side) pressure was applied through the hole in the upper end plug using bottled nitrogen as the pressurizing medium. Accordingly, the associated pressure system plumbing, including a bourdon tube pressure gauge, was connected to the threaded hole in the upper end plug. A clam-shell type electric resistance furnace was positioned around the specimen such that the 12-inch long sleeved region of the steam generator tube was centered within the 18-inch long heating zone of the furnace. The furnace was aligned to insure uniform heating around and long the length of the specimen. Thermocouples were installed along the steam generator tube to control and monitor the specimen temperature. A steel tubular protective shield was placed over the specimen, surrounding the specimen along its entire length, to prevent personal injury and heater element/equipment damage in the event the specimen failed under the imposed thermal, internal pressure, and axial cyclic loads.

In starting the test, the specimen was then first heated to the 600°F test temperature (See Figure 7-9). After a uniform test temperature was attained (along the sleeved portion of the steam generator tube) the specimen was then internally pressurized to approximately 1710 psig, the lower "B" end plug was secured within the lower testing machine grip (loading ram) to begin application of the cyclic loads. Prior to applying the cyclic loads for stages B and C of the axial fatigue test, the specimen internal pressure was reduced from 1710 to 1550 psig. The cyclic load magnitudes, loading ram stroke, number of load cycles, load cycle frequency, specimen temperature and specimen internal pressure were recorded.

7.3.1.4.4 Repeat Primary Side Hydrotest

Each of the five specimens was subjected to a repeat primary side hydrotest to provide assurance that the primary-to-secondary seal capability of the upper and lower sleeve-to-tube joint was maintained after exposure to the axial fatigue test loads. This test was conducted in accordance with the initial primary side hydrotest procedure of Paragraph 7.3.1.4.1.

7.3.1.4.5 Repeat Secondary Side Hydrotest

Each of the five specimens was subjected to a repeat secondary side hydrotest to provide assurance that the primary-to-secondary seal capability of the upper and lower sleeve-to-tube joint was maintained after exposure to the axial fatigue test loads. This test was conducted in accordance with the initial secondary side hydrotest procedure of Paragraph 7.3.1.4.2 (See Figures 7-5 and 7-6).

7.3.1.4.6 Tension Test

After the repeat primary and secondary side hydrotests, the specimens were subjected to room temperature tension tests (to failure) using a 20,000-pound capacity Instron uni- versal testing machine. Each specimen was subjected to tensile loading until specimen failure occurred. The load history, failure load, and the location and type of failure were recorded (See Figure 7-10).

7.3.1.5 Data Recording

See Table 7-1 for test results and data.

7.3.2 Upper Joint Strength Testing

7.3.2.1 Introduction

For the two previous sleeving operations at Ginna, the hydraulic expansion combined with the braze was considered as forming the sleeve-to-tube structural joint at the upper end of the sleeve. In the rapid sleeving concept, the braze at this joint is being considered as only forming the primary-to-secondary pressure boundary seal and not contributing to the load-carrying capability of the joint. Accordingly, this testing provided an evaluation of the explosive expansion alone in carrying the structural loads imposed on the upper joint under worst case service conditions. The test specimens, therefore, represented the upper end sleeve-to-tube joint and were assembled using the rapid sleeving installation processes, with the exception that the sleeves did not include the braze material or braze grooves. The sleeves were exposed to a prebraze/heat treat thermal cycle.

7.3.2.2 Specimen Design

Nine specimens, each modeling the upper end attachment joint of an installed sleeve, were fabricated and both fatigue and tension tested. The test specimen design is illustrated in Figure 7-7. Each of the specimen components are described in the following subsections.

7.3.2.2.1 Steam Generator Tube

The specimen steam generator tube section was cut from lengths of Inconel 600 nuclear grade tubing. This material complies with the ASME Section II Code requirements and is of the same size as the Ginna steam generator tubes. The nominal outside and inside diameters are 0.875 and 0.775 inch, respectively (0.050 inch wall thickness).

7.3.2.2.2 Bimetallic Sleeve

For this test, it is sufficient for the specimens to incorporate only the upper one-third length (12 inches) of an installation sleeve. The sleeve was explosively expanded into the tube to simulate an upper sleeve-to-tube joint, but the joint was not brazed to form a pressure seal since the load-carrying capability of the explosive expansion alone was investigated. However, the effect of the brazing operation on the strength of the joint was incorporated into the test specimens during assembly by subjecting the joint to a complete braze thermal cycle after the sleeve was explosively expanded into the tube. The normal braze temperature schedule established to braze a prebrazed sleeve into a steam generator tube was duplicated during the specimen joint braze simulation. Given these specimen design requirements, the specimen sleeves were not prebrazed. Accordingly, the two 1/4-inch wide, 360-degree circumferential grooves which would normally contain the BAu-4 gold braze alloy were not machined into the sleeve tubing. However, the specimen sleeves were exposed to the same 1825/1300°F temperature schedule employed to prebraze and heat treat the installation

sleeves. This approach produced equivalent specimen sleeves, having strength and upper joint characteristics similar to those of prebrazed installation sleeves.

7.3.2.2.3 Tube End Plugs

The end plugs described in the section entitled "Tube End Plugs" (Section 7.3.1.2.4) were installed.

7.3.2.3 Specimen Assembly

The specimens were fabricated by employing the same procedures, processes, and tooling applicable to the installation of the full-sized bimetallic sleeves in the Ginna steam generators. These procedures covered cleaning, explosive expansion at the upper sleeve-to-tube joint, and brazing of the upper joint.

7.3.2.4 Strength Testing

Each of the nine specimens was subjected to elevated temperature fatigue testing, followed by a room temperature tension test to failure. The test procedures, including descriptions of the facilities and instrumentation, are outlined below.

7.3.2.4.1 Axial Fatigue Test

Axial fatigue tests were performed identical to those performed in Section 7.3.1.4.3. The specimen was installed in the MTS frame by securing the "A" tube end plug within the upper grip. A clam-shell type electric resistance furnace was positioned around the specimen such that the expansion region of the

sleeve-to-tube joint was near the center of the furnace heating zone. The furnace was aligned to ensure uniform heating around and along the length of the specimen. Thermocouples were installed along the specimen to monitor and control the temperature. The specimen was heated to a uniform temperature of approximately 600°F. The "B" sleeve end plug was secured within the lower (loading ram) machine grip to begin application of the cyclic loads. The cyclic load magnitudes, loading ram stroke, initial joint slippage, number of load cycles, load cycle frequency and specimen temperature were continuously recorded during the axial fatigue test.

7.3.2.4.2 Tension Test

Tension tests were performed identical to those performed in the Section 7.3.1.4.6. After being fatigue tested, the specimens were subjected to room temperature tension tests (to failure) using the 20,000-pound capacity Instron uni- versal testing machine. Each specimen was subjected to tensile loading at a constant crosshead speed (pull rate) of approximately 0.05 inch per minute until specimen failure (sleeve pull-out) occurred. Before testing, the ends of the specimen were modified to make them compatible with the testing machine grips. This involved cutting off short lengths of the tube and sleeve--enough to remove the end plugs from the specimen--and swaging the last 4 inches of the steam generator tube "A" end down to 3/4 inch outside diameter. The applied tensile load was continuously recorded during the test until the sleeve was completely withdrawn from the steam generator tube.

7.3.2.5 Data Recording

See Table 7-2 for test results.

7.3.3 Leak Rate Testing

7.3.3.1 Introduction

In the rapid sleeving process, the upper sleeve-to-tube joint is formed by explosively expanding the prebrazed region of the sleeve into the steam generator tube, then creating a braze between the sleeve and tube along the expanded region through an induction heating technique. The braze is considered as only forming the primary-to-secondary pressure boundary seal and not contributing to the structural load-carrying capability of the joint. The integrity of the seal braze at the upper sleeve attachment joint is addressed as part of the design verification test phase of the rapid sleeving program. A safety related concern of the upper joint pertains to the leakage of reactor coolant through the joint in hypothetical instances where a defective braze is inadvertently formed during sleeve installation, or a braze fails in service during steam generator operation. To address this concern, tests were performed which established the leak limiting capability of three postulated joint braze conditions. These tests were performed on specimens which modeled the upper end sleeve-to-tube joint and involved determining the primary-to-secondary side leakage rates through the joint. The specimens were assembled using the rapid sleeve installation processes, with exceptions, to purposely create a particular braze joint condition. Accordingly, three different types

of specimens were fabricated, representing the three postulated joint braze conditions to be investigated (See Table 7-3 for specimen types).

7.3.3.2 Specimen Design

Nine specimens, each modeling the upper end attachment region of an installed sleeve, were fabricated and subjected to leak rate, fatigue, and tension tests. As Figure 7-7 illustrates, illustrates, each specimen essentially consisted of a section of steam generator tube into which the upper portion of a bimetallic sealable sleeve was explosively expanded to form the upper sleeve-to-tube structural joint. The installation technique and degree of expansion was the same as that expected for an actual steam generator sleeve installation. End plugs were brazed into the ends of the tube and sleeve to provide a means of gripping the specimen for the fatigue tests. They also served to seal the ends of the specimen, enabling the primary side to be pressurized with water during the leak rate tests. The three upper end joint conditions for which leak rates were determined were formed by applying certain installation processes to specimen sleeves which were prebrazed and sleeves for which the upper end expansion region was modified (no braze material and no braze grooves). Table 7-3 identifies the particular sleeve design and corresponding installation process which were combined to produce the three joint conditions that were investigated. Three specimens were fabricated for each of the three different upper joint conditions. The specimen components are described in detail in the following subsections.

Table 7-3 SUMMARY OF TEST SPECIMEN TYPES

Joint Condition	Number of Specimens To Be Tested	Sleeve Design	Sleeve Installation Process
1	3	No braze material, no braze grooves, but exposed to pre-braze thermal cycle.	Expanded only. Joint not exposed to braze thermal cycle.
2	3	No braze material, no braze grooves, but exposed to pre-braze thermal cycle.	Expanded; joint exposed to braze thermal cycle.
3	3	Prebrazed Specimens	Expanded; joint exposed to braze thermal cycle, but braze does not bond to tube.

7.3.3.2.1 Steam Generator Tube

The steam generator tube section (16 inches long) was cut from longer, as-received lengths of Inconel 600 nuclear grade tubing. This material complies with the ASME Section II Code requirements, and is of the same size as the Ginna steam generator tubes. The nominal outside and inside diameters are 0.875 and 0.775 inch, respectively (0.050 inch wall thickness).

7.3.3.2.2 Bimetallic Sleeve

For this test program, it is sufficient for the specimens to incorporate only the upper one-third length (12 inches) of an installation sleeve. For the

three specimens incorporating Joint Condition 3 (Table 7-3), the upper joint end of the sleeve was prebrazed, identical in design to that of the installation sleeves. For the six specimens incorp- orating Joint Conditions 1 and 2 (Table 7-3), the upper joint end of the sleeve was not prebrazed. Accordingly, the two 1/4-inch wide, 360-degree circumferential grooves which would normally contain the BAu-4 gold brazed alloy was not machined into the sleeve tubing at the upper joint region. These six specimen sleeves were exposed to the same 1825/1300°F temperature schedule employed to prebraze and heat-treat the installation sleeves. This exposure produced equivalent specimen sleeves, having strength characteristics similar to those of prebrazed installation sleeves.

7.3.3.2.3 Tube End Plugs

The tube end plugs provided a means of gripping the specimen for the fatigue tests and served to contain primary side pressure during the leak rate tests. They were machined from 304 stainless steel (See Figure 7-3). The plugs were positioned within the ends of the tube and sleeve, aligned with the specimen axis, and brazed to the inside diameter surface areas of the tube and sleeve.

7.3.3.3 Specimen Assembly

The specimens were fabricated by employing the same procedures, processes, and tooling applicable to the installation of the full-sized bimetallic sleeves in the Ginna steam generators. These procedures covered cleaning, explosive expansion at the upper sleeve-to-tube joint, and brazing of the upper joint.

7.3.3.4 Leak Rate Testing

Each of the nine specimens was subjected to a series of leak rate, fatigue, and tension tests. These tests are described below, listed in the order in which they were performed.

7.3.3.4.1 Leak Rate Determination

This test involved internally pressurizing the specimen at room temperature using water as the pressurizing medium and, while maintaining a constant test pressure, measuring the leakage of water from the primary to secondary side through the joint over a specific time period. The test was performed in a laboratory environment, such that the secondary side of the specimen was at ambient (0 psig, room temperature) conditions. In preparation for testing, the specimen was filled with water, connected to the pressurization system plumbing, and slightly pressurized to bleed air from the total system through the threaded hole in the upper end plug. As Figure 7-8 illustrates, the primary side pressure was generated by a continuously operating positve displacement pump. A back-pressure regulating valve, set at the test pressure of 1710 psig, and an accumulator were included in the system to provide a means of maintaining a constant, steady 1710 psig primary side pressure during the test. Leakage through the specimen joint was compensated for by make-up water supplied to the pump from a reservoir. The volume of water collected over the duration of the test was measured. At the start of testing, the specimen was slowly pressurized to 1710 psig. The

Pressure at which leakage initially occured was monitored on the bourdon tube pressure gauge attached to the specimen. Shortly after the 1710 psig test pressure was attained, the leakage from the test specimen began to be measured, the total after one hour represented the total leakage.

7.3.3.4.2 Axial Fatigue Test

The fatigue tests were performed using a 200,000-pound capacity MTS electro-hydraulic loading frame. The specimen was subjected to completely reversed axial cyclic loading at 600°F for a total of 21,700 load cycles. The applied loading fluctuated sinusoidally between peak tensile and compressive loads of 1,200 pounds (zero mean load) at a frequency of one load cycle per second.

The specimen was installed in the MTS frame by securing the "A" tube end plug within the upper grip. A clam-shell type electric resistance furnace was positioned around the specimen such that the center of the heating zone was near the expansion region of the sleeve-to-tube joint (See Figure 7-9). The furnace was aligned to ensure uniform heating around and along the length of the specimen. Thermocouples were installed along the specimen, within the heating zone of the furnace, to monitor and control the temperature. The specimen was heated to approximately 600°F and, after a uniform temperature was attained, the sleeve end plug was secured within the lower machine grip (loading ram) to begin application of the cyclic loads. The cyclic load magnitudes, loading ram stroke, initial joint slippage, number of load cycle frequency, and specimen temperature were continuously recorded during the axial fatigue test.

7.3.3.4.3 Repeat Leakage Rate Determination

The specimen was subjected to a repeat leakage test to determine the extent to which the leak-limiting capability of the upper sleeve-to-tube joint was affected by cyclic loading imposed on the joint. This test was conducted in accordance with the initial leakage test.

7.3.3.4.4 Tension Test

The nine specimens were subjected to room temperature tension tests (to failure) using a 20,000-pound Instron universal testing machine. Each specimen was subjected to tensile loading until specimen failure (sleeve pull-out) occurred. The applied tensile load was continuously recorded during the test until the sleeve was completely withdrawn from the steam generator tube.

7.3.3.5 Data Recording

See Table 7-4 for test results. Figures 7-5 and 7-10 represent the leak rate equipment set up and the tensile specimens.

7.3.4 Test Summary

The testing described in the previous sections illustrated the adequacy of the Rapid Sleeving System. The tooling tests described in Section 9.0 combined with the testing illustrate that the is a sealable sleeve meets the design requirements as identified in Section 5.0.

7.3.5 Corrosion Testing

The sleeve design incorporates an outer layer of nickel to resist caustic attack. The selection of nickel as a material for use in the Ginna application was based on extensive corrosion testing of various materials in an environment similar to that of the Ginna steam generator. The purpose of the corrosion testing was to assure that the sleeve and braze materials selected for the sleeve design provided a new pressure boundary which is superior to the existing tube pressure boundary from a corrosion standpoint. The corrosion tests were conducted using both elecro-chemical techniques that allowed corrosion to occur at an accelerated pace thereby enabling prediction of corrosion rates for the life of the sleeve, and long term tests in an unaccelerated environment. Nickel is the material most often used for corrosion resistance. As reported in the development document for the sixteen sleeve installation in 1981, Nickel 200 was shown to be superior to Inconel 600 for resistance to caustic intergranular attack (IGA). This corrosion test was conducted on Nickel 200 and Inconel 600 heat treated at 110°F and 1300°F in a 50% caustic solution at 550°F. This data revealed that on a general attack the 4 mill nickel layer on the O.D. of the Inconel 600 would last approximately 70 years when exposed to the caustic attack.

The braze material, BAu-4, was subjected to electrochemical tests and long term tests as follows:

1) The BAu-4 was subjected to electrochemical test at 350°F, 450°F, 550°F, and 600°F in a 50% caustic (N_aOH) plus 5% Na_2SO_4 solution. These results indicate the braze material will survive for the remaining life fo the plant.

Temp (°F)	BAu-4 (mpy)
350	2.6
450	14.6
550	65.2
600	77.2

2) Electrochemical tests of BAu-4 were conducted in NH_4-N_2H_4 water at 350°F, 450°F, and 550°F. The BAu-4 shows satisfactory results in this environment.

Temp (°F)	BAu-4 (mpy)	
350	0.3	0.95
450	0.3	0.75
550	0.3	0.7

3) Long term tests were conducted on the BAu-4 in a 50% N_aOH plus 5% Na_2SO_4 and in a primary water system chenistry environment. These tests llustrated the BAu-4 has satisfactory resistance to the environment.

The following were significant results of the corrosion test program:

1) Nickel 200 was shown to be superior to Inconel 600 for resistance to caustic intergranular attack (IGA).

2) The thickness of the nickel coating was established based on the expected operating life span of the steam generator.

3) The braze material (BAu-4) was shown to have excellent resistance to caustic intergranular attack.

4) No evidence of galvanic attack was noted in the corrosion test program.

TABLE 7-1

DESIGN VERIFICATION TESTING

SPEC.10	
Primary Hydro	- Passed
Secondary Hydro	- Passed
Fatigue	- 21,700 cycles
Primary Hydro	- Passed
Secondary Hydro	- Passed
Tension	- 11,100 lbs
* Tensile strength	- 90.7 ksi
SPEC. 11	
Primary Hydro	- Passed
Secondary Hydro	- Passed
Fatigue	- 21,700 cycles
Primary Hydro	- Passed
Secondary Hydro	- Passed
Tension	- 11,000 lbs
* Tensile Strength	- 89.9 ksi
SPEC. 12	
Primary Hydro	- Passed
Secondary Hydro	- Passed
Fatigue	- 21,700 cycles
Primary Hydro	- Passed
Secondary Hydro	- Passed
Tension	- 11,300 lbs
* Tensile Strength	- 92.3 ksi
** SPEC. 13R	
Primary Hydro	- Passed
Secondary Hydro	- Passed
Fatigue	- 21,700 cycles
Primary Hydro	- Passed
Secondary Hydro	- Passed
Tension	- 10,800 lbs
* Tensile Strength	- 88.2 ksi
SPEC. 14	
Primary Hydro	- Passed
Secondary Hydro	- Passed
Fatigue	- 21,700 cycles
Primary Hydro	- Passed
Secondary Hydro	- Passed
Tension	- 10,700 lbs
* Tensile Strength	- 87.4 ksi

* The Tensile Strength is based on a nominal sleeve cross section in the mid-span of the sleeve. Specimen 10, 11, and 14 failed at the lowest edge of the braze grooves and Specimen 12 failed at a scratch in the sleeve in mid-span.

** Specimen 13 original failed initial hydro due to leakage through the braze region. The failure analysis of Specimen 13 is the topic of a separate report.

TABLE 7-2

UPPER JOINT STRENGTH

(All Specimens Expanded Only)

SPEC. 1 Fatigue: 21,700 cycles Tension: 4,400 # slip 6,400 # max	SPEC. 4 Fatigue: 21,700 cycles Tension: 4,200 # slip 6,400 # max	SPEC. 7 Fatigue: 21,700 cycles Tension: 4,300 # slip 5,700 # max
SPEC. 2 Fatigue: 21,700 cycles Tension: 4,300 # slip 6,200 # max	SPEC. 5 Fatigue: 21,700 cycles Tension: 4,200 # slip 6,100 # max	SPEC. 8 Fatigue: 21,700 cycles Tension: 4,300 # slip 6,300 # max
SPEC. 3 Fatigue: 21,700 cycles Tension: 4,500 # slip 5,900 # max	SPEC. 6 Fatigue: 21,700 cycles Tension: 4,200 # slip 6,100 # max	SPEC. 9 Fatigue: 21,700 Tension: 4,100 # slip 6,000 # max

TABLE 7-4

LEAK RATE TESTING RESULTS

	EXPANDED ONLY, NO BRAZE MAT'L.	NO BRAZE MAT'L., EXPANDED PLUS BRAZE THERMAL CYCLE	EXPANDED, PLUS BRAZE THERMAL CYCLE <u>WITH</u> BRAZE MATERIAL.
UNCONSTRAINED DURING LEAK TEST	SPEC. 15 <u>3</u> MIL EXP. 1. LEAK: 8 ML IN 1st HR (3.5226×10^{-5} GPM) 2. FATIGUE: 21,700 cycles 3. LEAK: 7.2 ML/HR (3.110×10^{-5} GPM) 4. TENSION: 1750 # slip 6950 # max	SPEC. 18 <u>12</u> MIL EXP. 1. LEAK: 2 ML IN 1st HR (8.8066×10^{-6} GPM) 2. FATIGUE: 21,700 cycles 3. LEAK: 355 ML/HR (1.5631×10^{-3} GPM) 4. TENSION: 4000 # slip 6100 # max	SPEC. 21 <u>7</u> MIL EXP. 1. LEAK: 1/2 ML IN 1st HR (2.2016×10^{-6} GPM) 2. FATIGUE: 21,700 cycles 3. LEAK: 1.4 ML/HR (6.1646×10^{-6} GPM) 4. TENSION: 1500 # slip 5800 # max
CONSTRAINED DURING LEAK TEST	SPEC. 16 <u>4</u> MIL EXP. 1. LEAK: 100 ML IN 1st HR (4.4033×10^{-4} GPM) 2. FATIGUE: 21,700 cycles 3. LEAK: 510 ML/HR (2.2457×10^{-3} GPM) 4. TENSION: 4000 # slip 7100 # max	SPEC. 19 <u>4</u> MIL EXP. 1. LEAK: 65 ML IN 1st HR (2.8621×10^{-4} GPM) 2. FATIGUE: 21,700 cycles 3. LEAK: 20 ML/HR (8.8066×10^{-5} GPM) 4. TENSION: 3500 # slip 5700 # max	SPEC. 22 <u>7</u> MIL EXP. 1. LEAK: 1.2 ML IN 1st HR (5.2840×10^{-6} GPM) 2. FATIGUE: 21,700 cycles 3. LEAK: 47 ML/HR (4.6455×10^{-3} GPM) 4. TENSION: 3000 # slip 5900 # max
	SPEC. 17 <u>7</u> MIL EXP. 1. LEAK: 140 ML IN 1st HR (6.1646×10^{-4} GPM) 2 FATIGUE: 21,700 cycles 3. LEAK: 650 ML/HR (2.8621×10^{-3} GPM) 4. TENSION: 4100 # slip 7700 # max	SPEC. 20 <u>8</u> MIL EXP. 1. LEAK: 51 ML IN 1st HR (2.2457×10^{-4} GPM) 2. FATIGUE: 21,700 cycles 3. LEAK: 315 ML/HR (1.387×10^{-3} GPM) 4. TENSION: 1500 # slip 6000 # max	SPEC. 23 <u>8</u> MIL EXP. 1. LEAK: 54 ML IN 1st HR (2.3778×10^{-4} GPM) 2. FATIGUE: 21,700 cycles 3. LEAK: 47 ML/HR (2.0695×10^{-4} GPM) 4. TENSION: 3700 # slip 6000 # max

PROPRIETARY

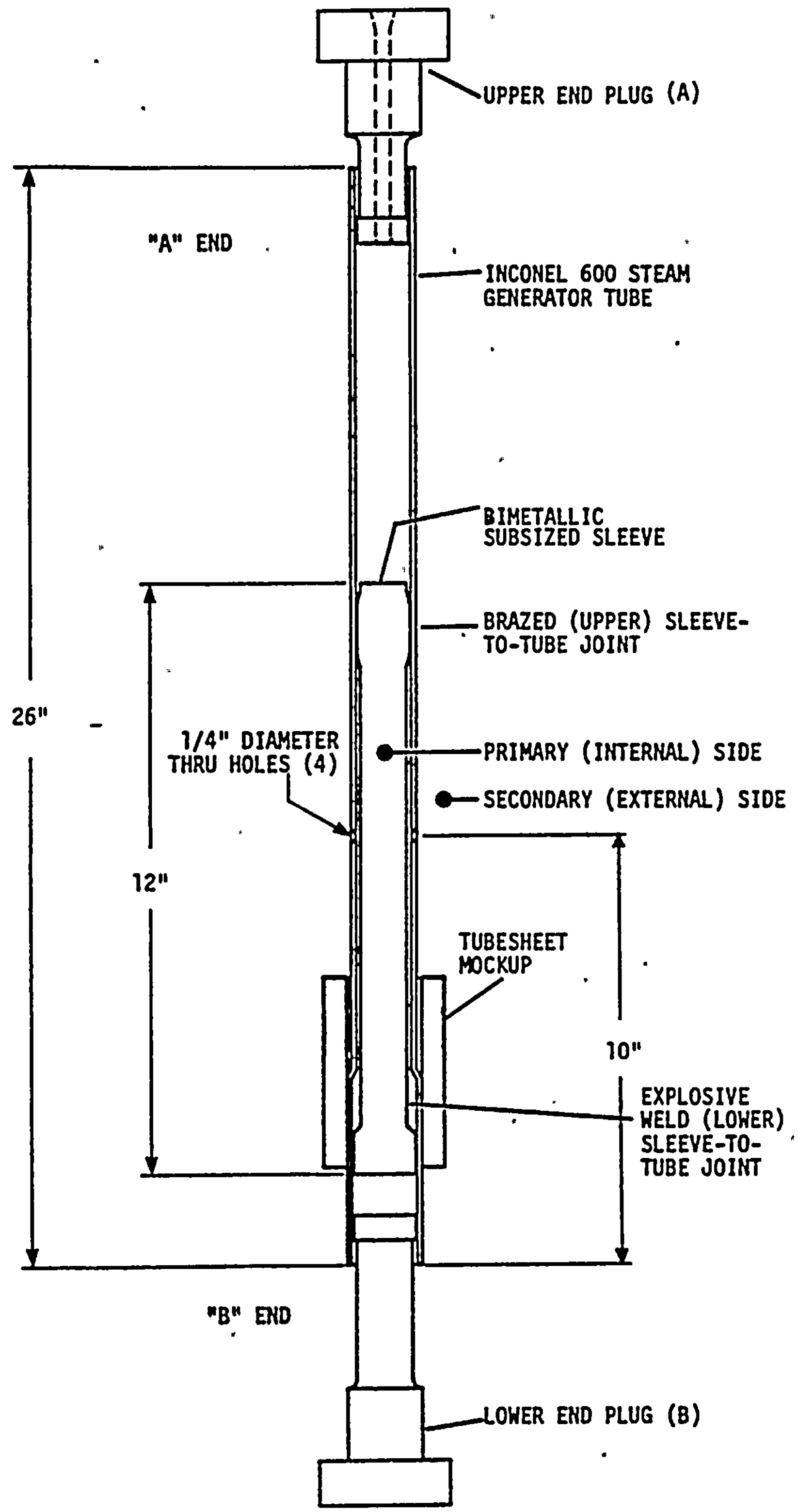


Figure 7-1 Schematic of Design Verification Test Specimen

PROPRIETARY

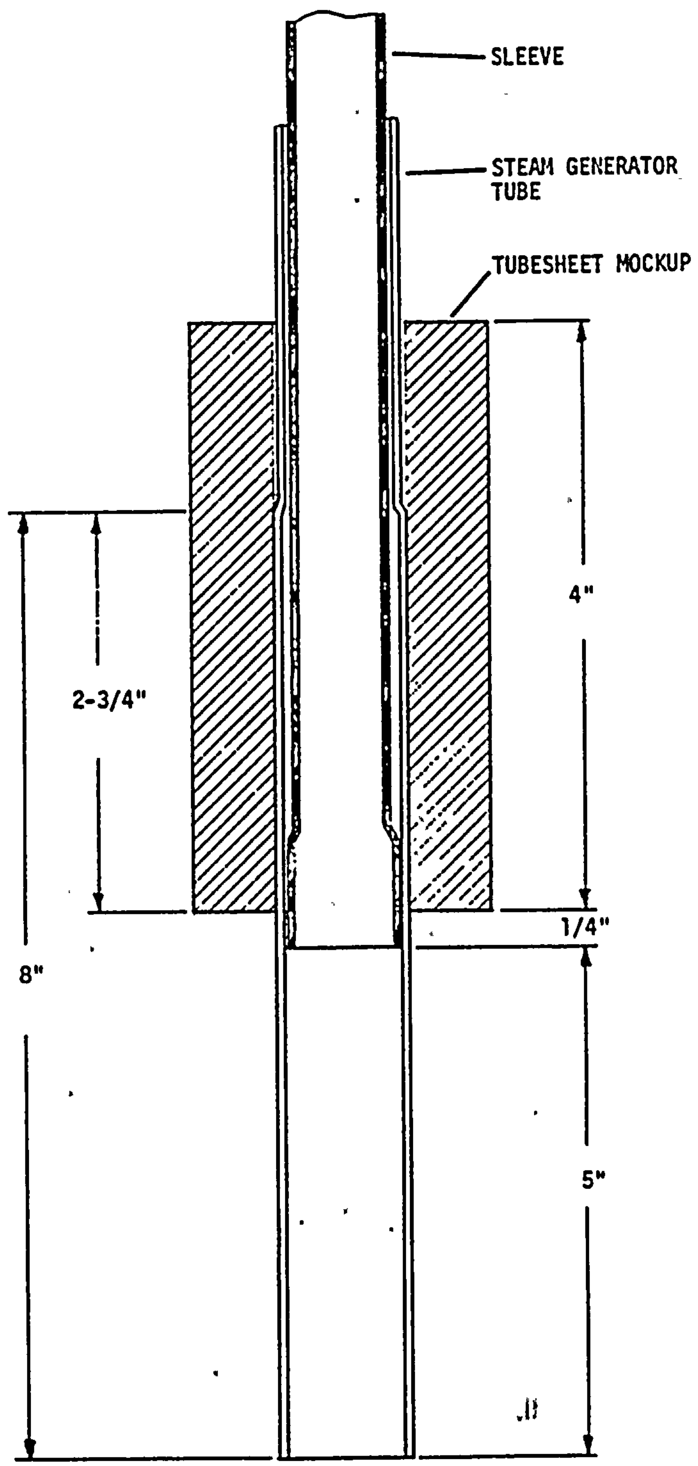


Figure 7-2 Detail of Lower Sleeve-to-Tube Joint Region of Design Verification Test Specimen (Before Explosive Weld)

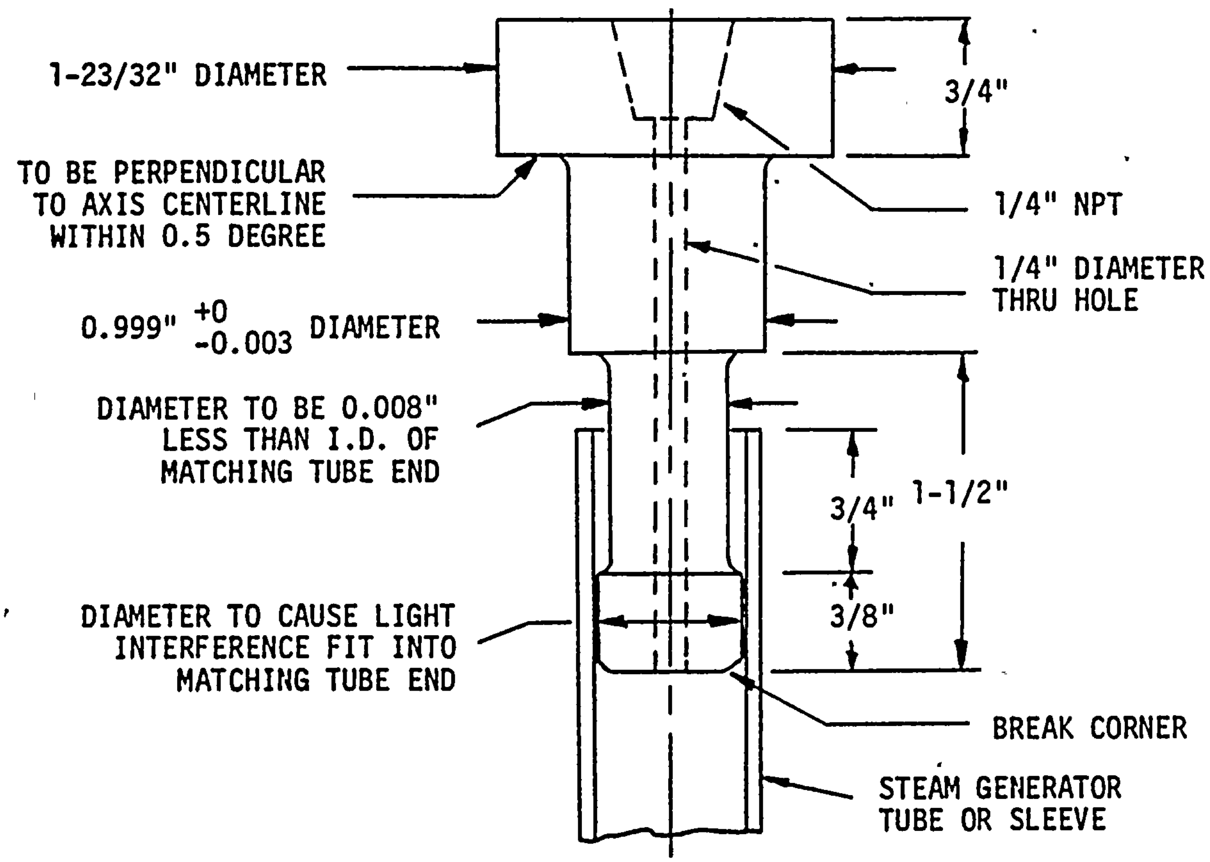


Figure 7-3 Design of End Plugs for Upper Joint Leak Rate Test Specimen

End Plug "A" - As shown

End Plug "B" - #1 change 1-1/4" length dimension to 6"
- #2 eliminate thru-hole and 1/4" NPT

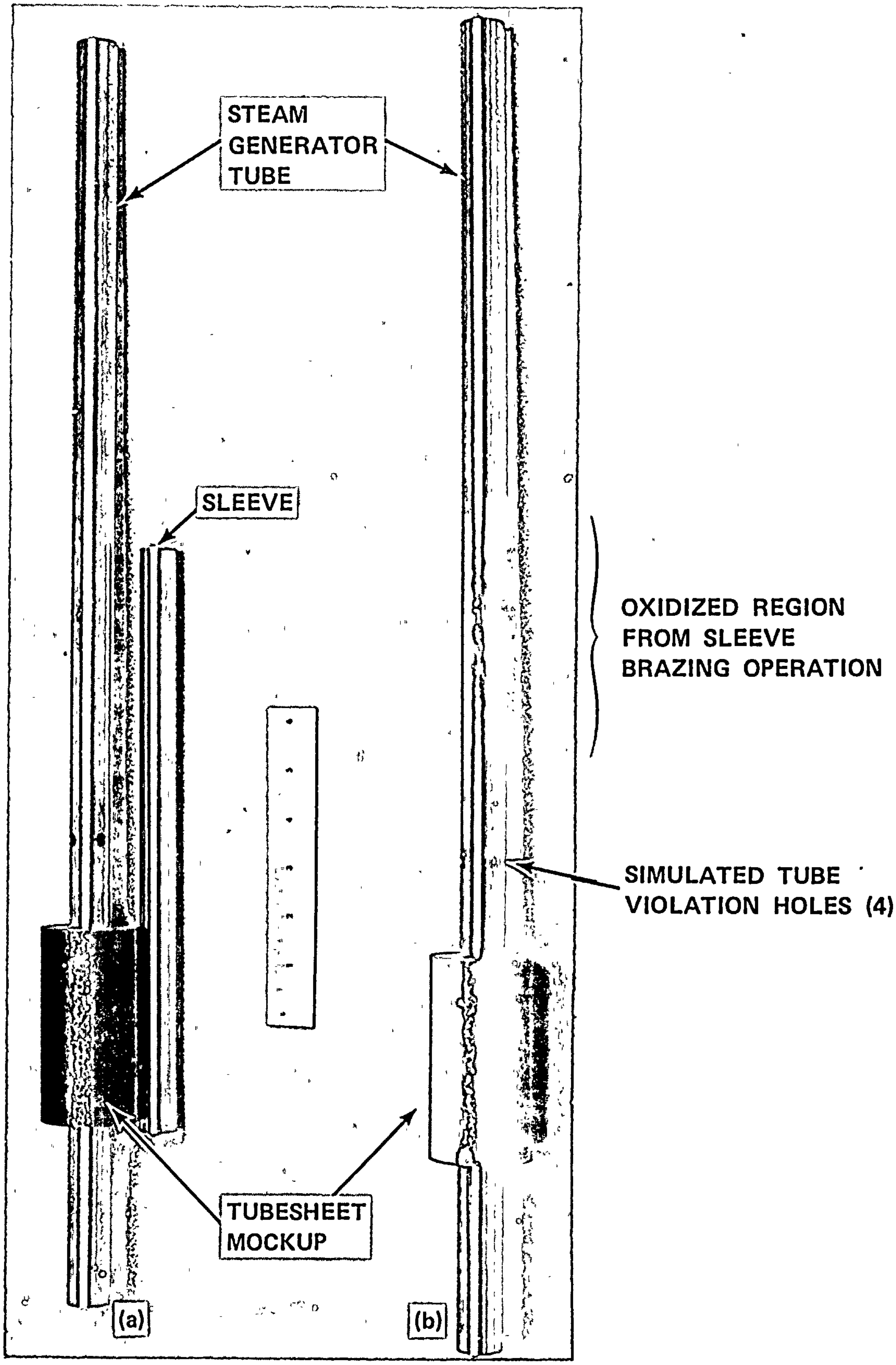
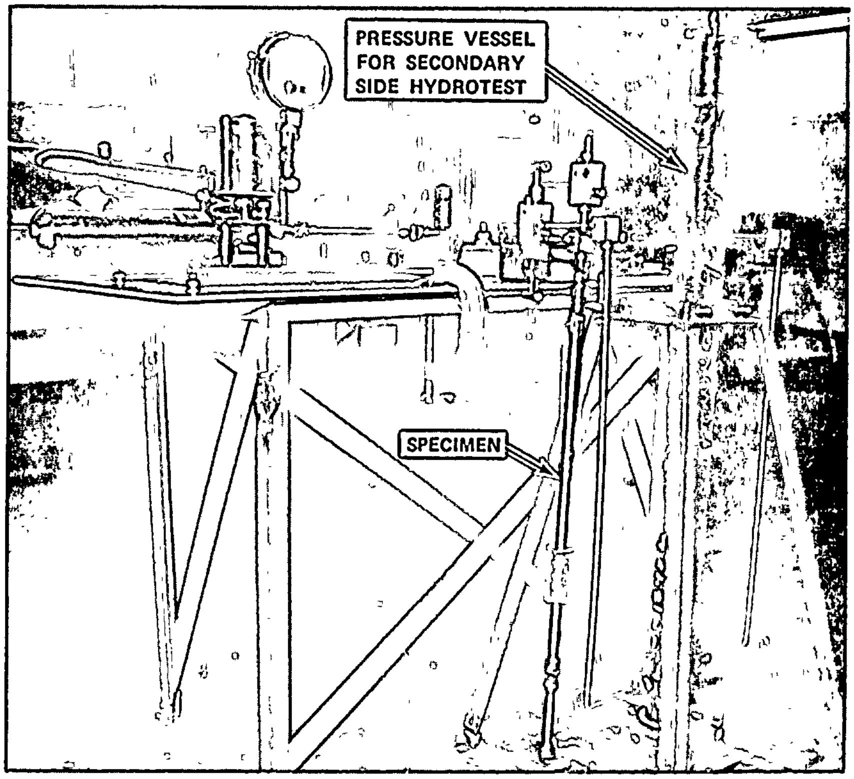


FIGURE 7-4. Arrangement of (a) Preassembled and (b) Assembled Design Verification Test Specimen



Specimen Undergoing Primary Side Hydrotesting

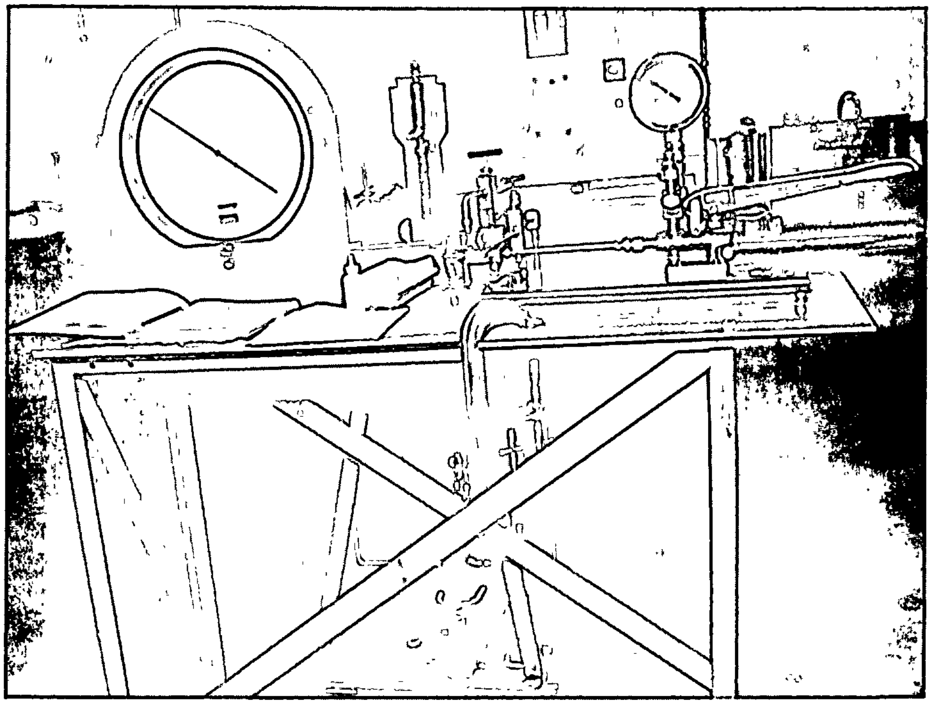


FIGURE 7-5. Hydraulic Hand Pump and Pressure Gage Used for Primary and Secondary Side Hydrotesting

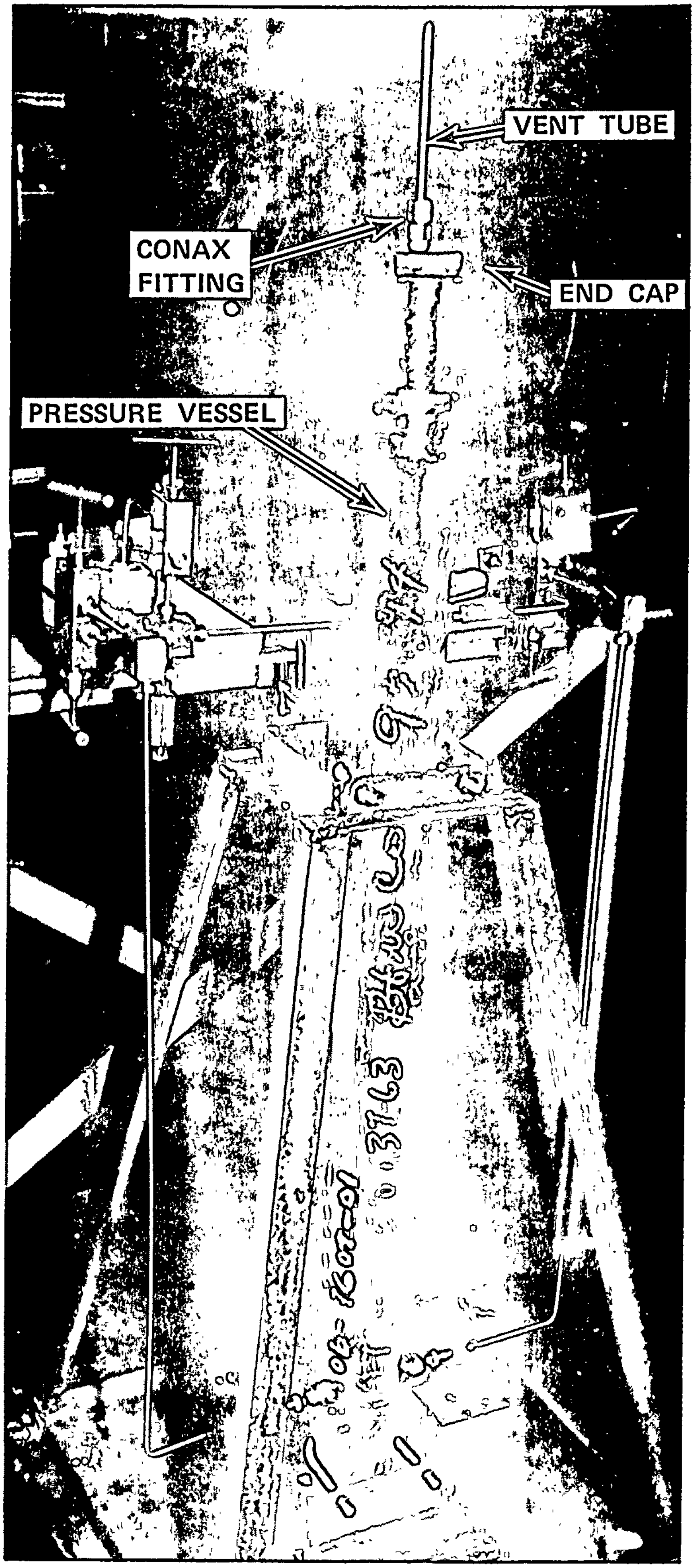


Figure 7-6 Specimen Undergoing Secondary Side Hydrotesting Inside Pressure Vessel

PROPRIETARY

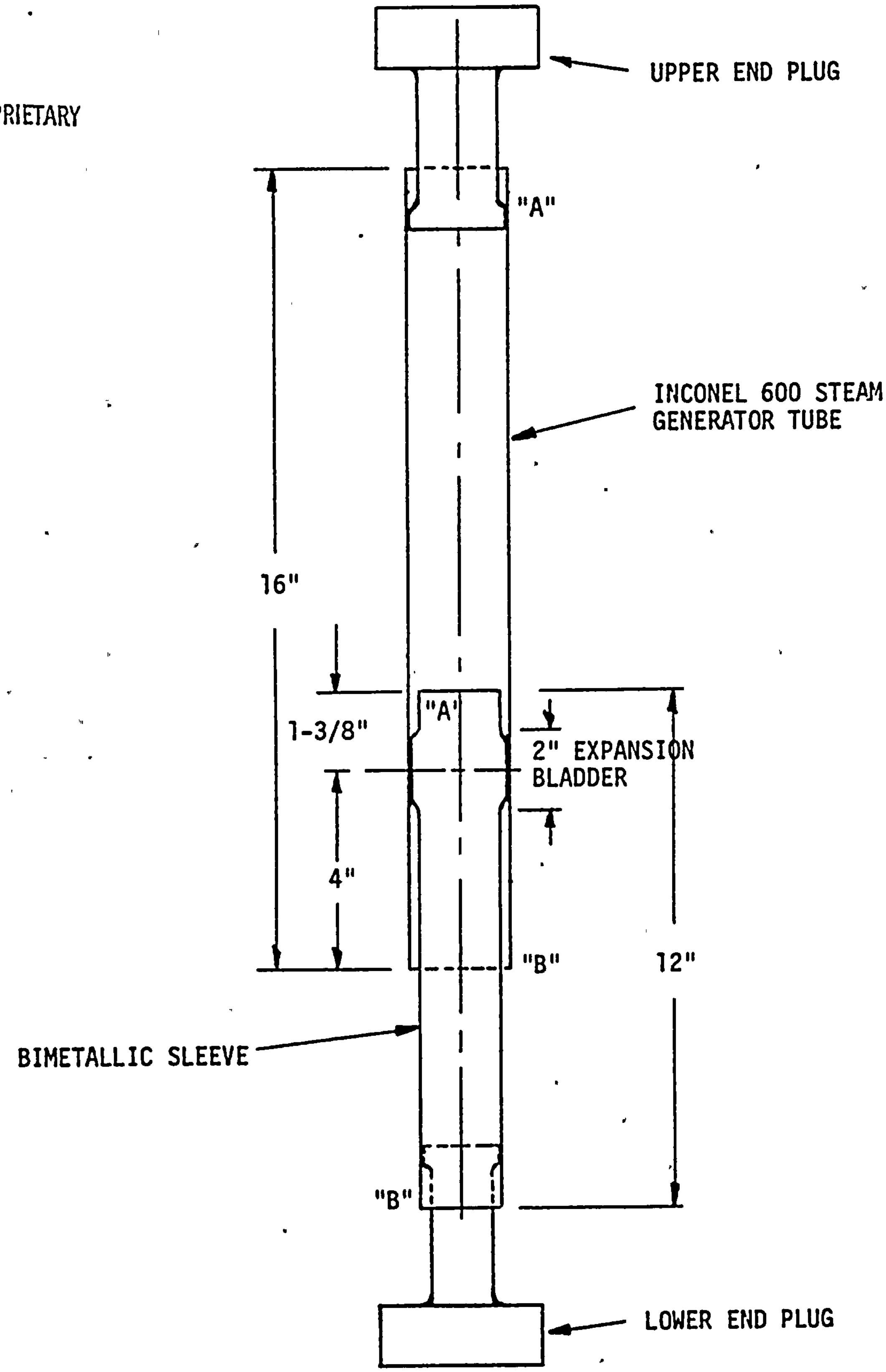


Figure 7-7 Design of Upper Sleeve-to-Tube Joint Strength and Joint Leak Rate Test Specimen

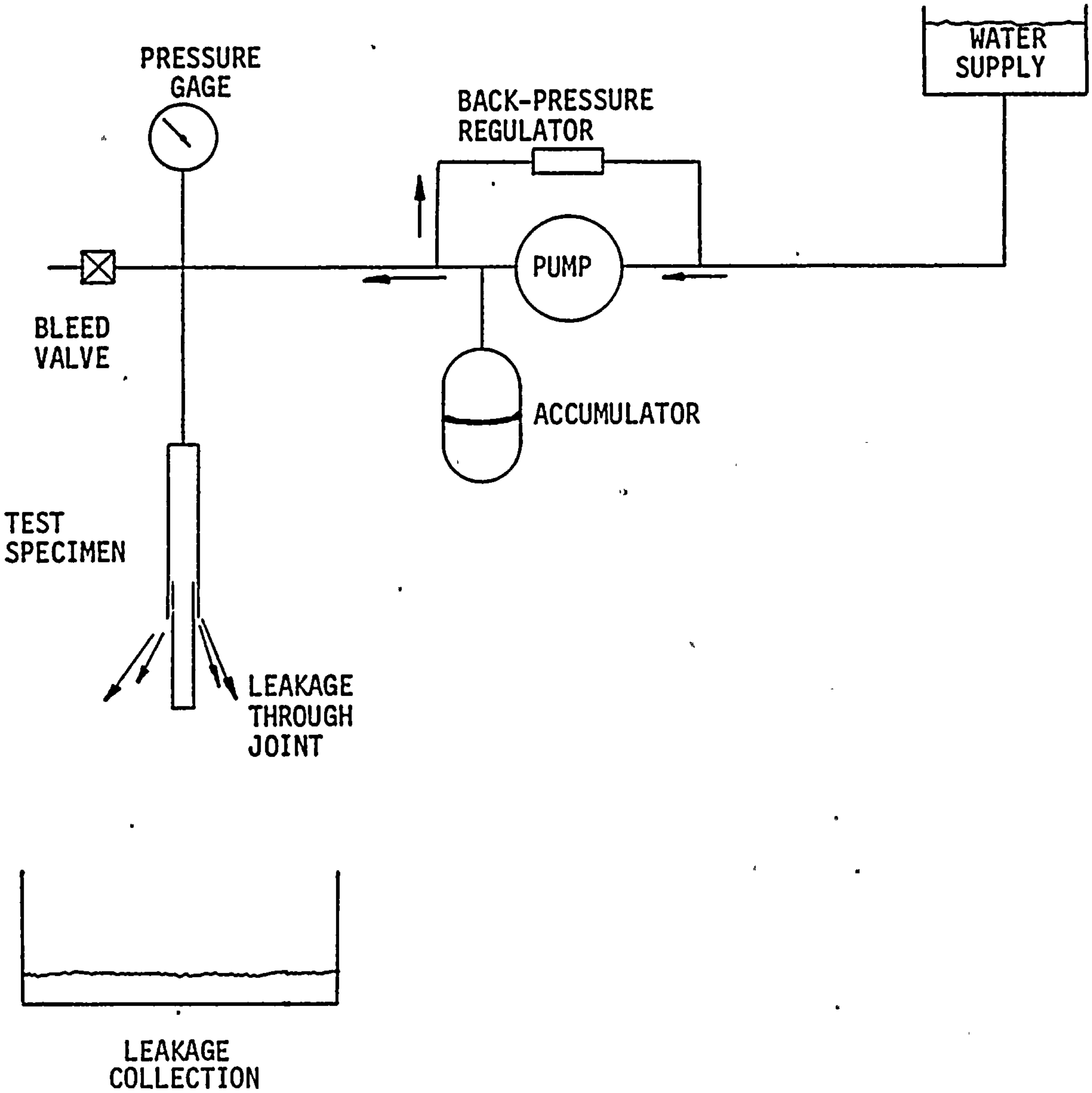


Figure 7-8 Schematic of Upper Joint Leakage Test Setup

PROPRIETARY

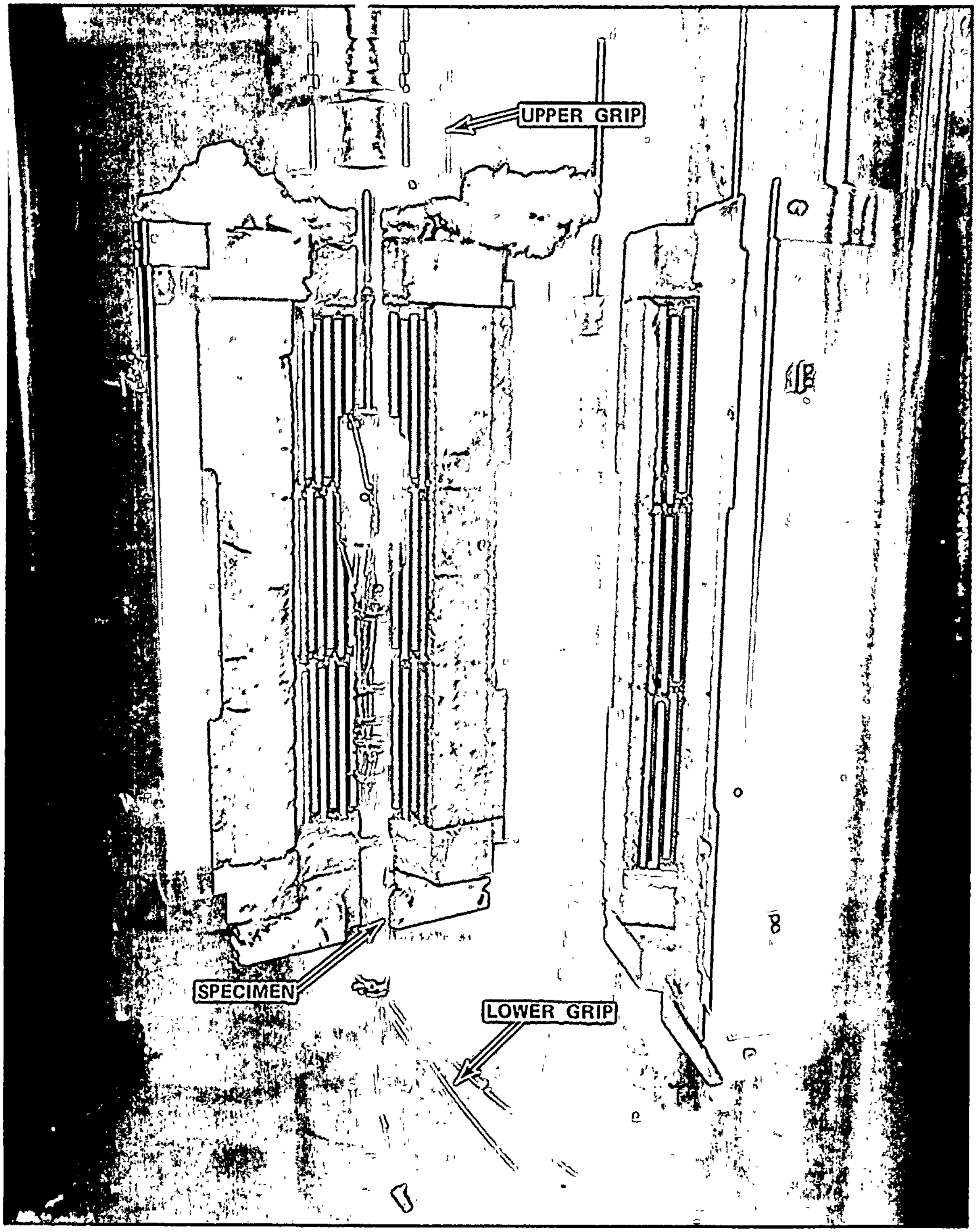


FIGURE 7-9. Specimen Installed in
MTS Loading Frame for Axial Fatigue Test at 600ºF

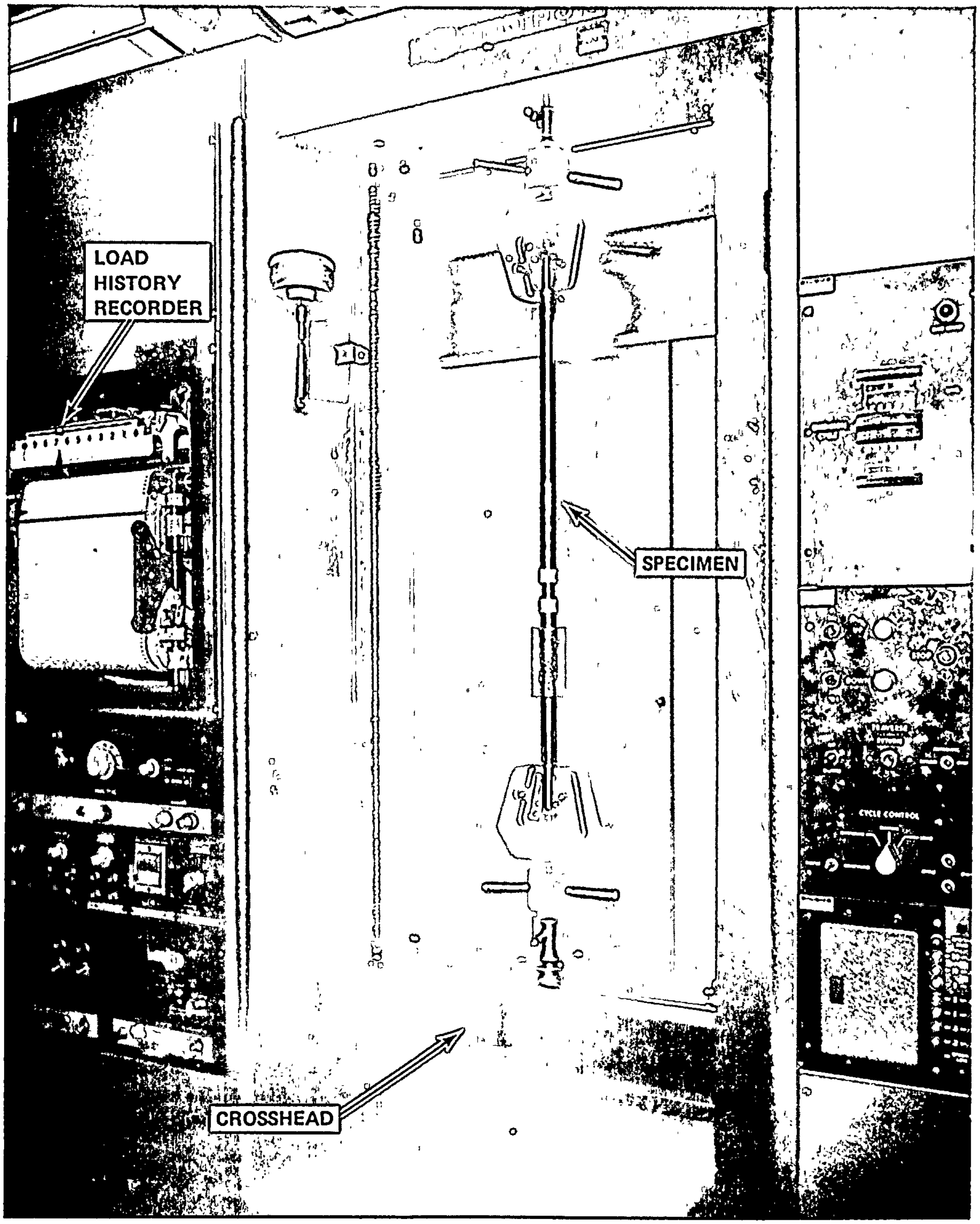


FIGURE 7-10. Specimen Undergoing
Tension Testing in Instron Testing Machine

8.0 ANALYSIS

This section of the report summarizes the results of the analyses performed to demonstrate that the sleeve meets the RG&E design requirements. The stress fields in both the sleeve and the parent steam generator tube, in the as-installed geometry, are described. In addition, this section shows that the sleeve can accept the design loadings without failure and is qualified as a primary pressure boundary.

8.1 Rapid Sleeving Analysis Summary

When an inspection indicates that the pressure boundary of a steam generator tube has been degraded, the tube either must be repaired or removed from service. An innovative repair process involves "sleeving" the defective tube area. Analyzing this sleeve uses the ASME Code.

The stress analyses performed using design criteria parameters summarized in Section 5.0 are briefly presented in the ensuing pages. The structural integrity of the tube/sleeve assembly was analyzed with respect to pressure, through wall thermal/gradient effects, and axial, thermal, and pressure loadings. The following is a summary of the analysis results for the maximum primary stress, primary plus secondary stress, and the fatigue usage factor.

Maximum Primary Stress Intensity Range-Design Conditions

Sleeve ($P_L + P_b$ - primary local membrane plus bending)

$S = 16.2$ ksi $< 1.5\ S_m = 34.95$ ksi

Tube ($P_L + P_b$ - primary local membrane plus bending)

$S = 13.9$ ksi $< 1.5\ S_m = 34.95$ ksi

Maximum Primary Plus Secondary Stress Intensity Range

Sleeve - $S = 37.3$ ksi $< 3 \cdot S_m = 69.9$ ksi

Tube - $S = 30.2$ ksi $< 3\ S_m = 69.9$ ksi

Maximum Cummulative Fatigue Usage Factor

$U_T = 0.01 <$ Allowable Usage Factor $= 1.0$

Maximum Primary Stress Intensity Range - Level D Conditions (1)

Sleeve (P_m - primary membrane)

$S = 35.08$ ksi $< 2.4\ S_m = 55.92$ ksi

Note: 1) The tube is in an assumed severed condition such that the sleeve carries all axial loads.

Not only have the sleeve upper and lower joints been analyzed in accordance with the ASME Code, Section III, but the tube/sleeve assembly braze, explosive expansion and explosively welded joints have also been extensively tested. These tests have satisfactorily demonstrated the sleeve's ability to resist the axial cyclic loadings that the tube/sleeve assembly would experience during the remaining plant design life. The axial load fatigue testing verified the braze, explosive expansion, and explosive weld shear strength integrity for their specified loadings.

8.2 Analysis Loading Cases

Stress categories whether primary, secondary or peak for the sleeve or tube will be contingent on the following load conditions:

Design
Normal Operating Conditions (Level A/B)
Pressure Transients
Thermal Transients
Seismic
Faulted Conditions (Level D)

These required load conditions are listed in Table V of the design criteria document. A description of the specific loadings associated with each of the above conditions is presented in the following sections.

8.2.1 Design Calculations

This section documents prepared calculations which demonstrate the tube/sleeve design (Figures 8-1, 8-2 and 8-3) meets the internal design pressure requirements of paragraph NB-3324 of the ASME Code, Section III. The sleeve has a bimetallic material construction consisting of stress-relieved Inconel 600 coextruded with a Nickel 200 outer surface. The yield strength and design stress intensity values are tabulated in Table 8-2 as a function of temperature. The tube is made of mill-annealed Inconel 600. The yield strength and design stress intensity values are given in Table 8-3. All values for the linear coefficient of thermal expansion and the modulus of elasticity are taken directly from the ASME Code Section III, Appendices.

The calculations for internal design pressure are based on the following conditions:

1. A steam generator tube of 0.875 inch OD x .050 inch average wall thickness with the lower 2 3/4 inches rolled into a 0.888 inch to 0.893 inch diameter hole in the 22 inch thick tubesheet (Figure 8-1).

2. A primary side design pressure of 2485 psig and temperature of 650°F.

3. A secondary side design pressure of 1085 psig and temperature of 600°F.

4. A sleeve of 0.745 inch OD except at the attachments (Figures 8-1, 8-2, and 8-3).

Calculations for the sleeve internal pressure sizing are below. The results are:

Parameter	Calculated	Design
Thickness (Minimum) t, inches	0.038	0.040 (1)

(1) .044 inch minimum specified for tubing manufacture, .040 inch minimum allowed under expanded braze material grooves, (Figure 8-3).

PRIMARY PRESSURE (Criteria of NB-3324.1, ASME Code, Section III)

Tube

OD = 0.875 inch
$t = P\,(OD)/2\,(S_m + 0.5P)$
P = 2485 psi (Table 8-4)
S_m = 23300 psi (Table 8-3)
t = 2485 (0.875)/2 (23300 + 1242.5)
t = 0.045 inch (minimum required pressure thickness)

Sleeve (non-expanded region)

OD = 0.747 inch (maximum)
S_m = 23330 psi (Table 8-2)
t = 2485 (0.747)/2 (23300 + 1242.5)
t = 0.038 inch (minimum required pressure thickness)

Sleeve (expanded region)

OD = 0.788 inch (Figure 8-3)
t = 2485 (0.788)/2 (23300 + 1242.5)
t = 0.040 inch (minimum required pressure thickness)

The ASME Code is very conservative in calculating external pressure capacity and testing is usually performed to define specific collapse pressure compared to design requirements. An extrapolated collapse pressure value of 2630 psi for RG&E tube was obtained by using data from external pressure tests on similar tubes. This value is greater than the RG&E design pressure. In addition, ASME Code calculations were prepared which demonstrate that the sleeve is better than the generator tube from an external pressure capacity.

External pressure calculations were performed using the procedure in NB-3133.3(a) of the ASME Code, Section III. The material factor A, as a function of the tube parameters L/D_0 and D_0/t, is read from Figure VII-1100-1. Using factor A and Figure VII-1102-1, factor B is determined. The maximum allowable external pressure is then calculated per Step 7 of NB-3133.3(a).

Using the above criteria, a typical steam generator tube has a calculated external pressure capacity of 808 psi. A typical sleeve has a calculated external pressure capacity of 984 psi and 853 psi in the non-expanded and expanded regions, respectively. The calculations for the external pressure are on the following page.

EXTERNAL PRESSURE (Criteria of NB3133.3, ASME Code, Section III)

Tube

D = 0.875 inch
thickness = 0.050 inch
D/t = 0.875/0.050 = 17.5
L/D = 33/0.875 = 37.7
A = 0.0037, Figure VII-1100-1, ASME Code
B = 10600, Figure VII-1102-1, ASME Code
P_a = 4B/3(D/t)
P_a = 4 (10600) (0.050)/3(0.875)
P_a = 808 psi

Sleeve (non-expanded region)

D = 0.745 inch
thickness = 0.050 inch
L = 33 inch
D/t = 0.745/0.05 = 14.9
L/D = 33/0.745 = 44.3
E = 29.2 x 10^6 psi
A = 0.005, Fig. VII-1100-1, ASME Code
B = 11000, Figure VII-1102-1, ASME Code
P_a = 4B/3(D/t)
P_a = 4 (11000) (0.050)/3(0.745)
P_a = 984 psi

Sleeve (expanded region)

D = 0.788 inch, Ref. 3
thickness = 0.047 inch, Ref. 3
L = 33 inch
D/t = 0.788/0.047 = 16.8
L/D = 33/0.788 = 41.9
E = 29.2 x 10^6 psi
A = 0.004, Fig. VII-1100-1, ASME Code
B = 10700, Fig. VII-1102-1, ASME Code
P_a = 4B/3(D/t)
P_a = 4(10700)(0.047)/3(0.788)
P_a = 853 psi

8.2.2 Normal Operating Conditions

The pressures and temperatures for normal operating conditions at 100% power taken from the design criteria document, are as follows:

Primary side pressure	2235 psig
Steam pressure	766 psig
Primary side inlet temperature	605.4°F
Primary side outlet temperature	551.8°F
Steam temperature	515.4°F

8.2.2.1 Pressure Transients

From the design criteria document the critical pressure transients were selected and tabulated in Table 8-5. By comparing the differential pressure it was found that the pressure transients could be grouped as in Table 8-6. These pressure changes were evaluated along with the accompanying transient thermal changes and thermal gradient effects. The pressure transient groupings shown in Table 8-6 would provide a conservative usage factor calculation for the given design.

8.2.2.2 Thermal Transients

In the design criteria document the temperature changes in the steam generator primary and secondary sides are described graphically. These thermal transients are tabulated in Tables 8-7 and 8-8 to show the temperature ranges, temperature gradients and the corresponding number of design cycles.

The tube/sleeve thermal transient analysis determines the fatigue life of the assembly. To determine the total useful life for normal operating conditions, usage factors from all contributing normal operating transients are combined.

The transients listed in Tables 8-7 through 8-10 were considered for the fatigue life. All of the transients except transient 4 contribute an insignificant amount to the fatigue life. When all their contributions are combined the total usage factor is small (usage factor equals 0.01).

The thermal conditions considered for each transient are as follows:

1. Initial equilibrium.
2. Intermediate thermal equilibrium.
3. Final thermal equilibrium condition.

Few of the transients described in Tables 8-7 and 8-8 return to the transient initial starting condition. Therefore, these transients were extended linearly to shutdown, 0% load, or 100% load depending upon the nature of the transient.

Thus the following transient groups were combined:

Group 1 - Consists of transients 1 and 4 from Table 8-9. Total number of required fatigue cycles is 200. (Transient 4 is a continuation of 1.)

Group 2 - Consists of transients 6, 7, 8, 9, 10 and 11 from Table 8-9. Total number of required fatigue cycles is 14980 (use 15000).

Group 3 - Consists of transients 2, 3 and 5 from Table 8-9. Total number of required fatigue cycles is 14980 (use 15000).

These cases are retabulated in Table 8-10 and are used in the thermal analysis to obtain the tube/sleeve assembly thermal stresses. By examining each case in Table 8-9, the enveloping of these three groups were determined.

8.2.2.3 Seismic

The design criteria documents acceleration factors to be used for OBE and SSE seismic considerations. These factors were applied to the tube/sleeve assembly utilizing a static analysis method. The method used and the results are discussed in Section 8.5

8.2.3 Faulted Conditions (Level D)

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 is located at the top of the tubesheet, the LOCA and SSE bending stresses in the sleeve are quite small. The governing Level D event for the sleeve therefore is a postulated secondary side blowdown (main steam line break, MSLB). The axial loading and internal pressure are specified in the design criteria document. The method used and results are discussed in Section 8.4.2.3.

8.3 Tube/Sleeve Analysis

This section documents the stress evaluation of the tube/sleeve assembly in relation to the requirements of the Design Criteria and with respect to allowable stress criteria in the ASME Code, Section III. A finite element analysis of the tube/sleeve assembly was performed using the following B&W computer codes:

(1) FESAP - "Finite Element Structural Analysis Program" - Version 6.3.

(2) FETAP - "Finite Element Thermal Analysis Program" - Version 4.1.

(3) CLASS - "Finite Element Stress Classification Program - Version 1.0.

The sleeve configuration analyzed is shown in Figures 8-1, 8-2 and 8-3 and the base dimensions are in Table 8-1.

8.3.1 Method of Analysis

In order to validate the structural integrity of the sleeve design (see Figures 8-1 through 8-3), a thermal/mechanical finite element analysis was performed. B&W Computer Codes FESAP, FETAP and CLASS were used. Their application to the solution of the problem is summarized as follows:

Computer code "FESAP" is a program for the analysis of structures using the finite element method. Such a procedure is derived from variational principles and based on the fundamental theories of applied mechanics. The program can be used to analyze efficiently a large variety of finite element models of structures in one, two or three dimensions.

Computer code "FETAP" is a program which performs both steady-state and transient heat conduction analyses. It provides thermal distribution output on any arbitrary solid with constant or temperature-dependent material properties. One-, two-, and three-dimensional elements may be used individually or together in the finite element grid representation of the solid structure.

Computer code "CLASS" is a post-processing program which when linked to two-dimensional stress calculating programs calculates stresses at designated points and for a series of points in a straight line. CLASS resolves the individual element stresses into the equivalent membrane, bending and peak components of stress across the section. It performs stress classification according to ASME Code, Section III.

The portion of the tubesheet modeled was based on a calculated effective radial area surrounding the tube. This radial representation approximates the tubesheet radial stiffness surrounding the tube. Figure 8-4 a representation of the tubesheet hole pattern geometry and a calculation of the effective radial area surrounding the tube. The tubesheet was modeled through the tube rolled expansion area. The FESAP/FETAP axisymmetric models were developed in accordance with dimensions in Table 8-1. The finite element models used for the tube/sleeve upper and lower joints are shown in Figures 8-5 and 8-6.

In the radial direction, the existence of bending moment would be apparent by a variation in stresses across the thickness. Thus in expected critical stress areas, additional nodes were used along the radial element edges. In less critical sections, a minimum number of nodes were used. In the axial direction, any change which occurs is over a much greater distance than the sleeve or tube wall thickness. Thus, in the axial direction a minimum number of nodes was used.

The model has few constraints on expansion. The thermal expansion of the tubesheet places minimal radial constraint on the tube. Further, since the tubesheet responds almost instantaneously to the primary coolant temperature it is assumed that the sleeve, tube, adjacent tubes and/or sleeves and the tubesheet are soaked at the primary inlet fluid temperatures. To conservatively account for the tube axial thermal gradient at the top of the tubesheet, the tube is assumed to be saturated at the primary inlet fluid temperature through the first 16.5 inches of the tubesheet (75% of the tubesheet thickness). From this point the tube temperature varies linearly to the secondary side temperature at the top of the

tubesheet. The thermal effect of the sludge buildup was not modeled since its effect is to insulate the tubesheet thereby decreasing any axial thermal gradient through it. These assumed heat transfer boundary conditions result in a conservative distribution of thermal gradients. Also, no restriction to pressure expansion (restriction due to tubesheet stiffness) along the tube outer surface above the roll expansion region is input. This permits conservative bending stresses to be developed in the lower sleeve attachment and tube wall. To support the model the nodes in the vicinity of the lower face of the tubesheet (tube-to-tubesheet weld) were constrained to have zero displacement in the axial direction.

To simplify the analysis model, a portion of the tube and sleeve between the sleeve expanded end joints was modeled by a combination of beam elements. This portion of the assembly is primarily influenced by axial loading. Thus, the upper and lower axisymmetric models were connected.

An end load (tube is a closed end cylinder) was applied to the top of the tube section being modeled. This approximates the axial tension created by the differential internal and external pressure loading.

Effective internal pressure area of the tube cross section:

Area = $(0.785)\ (0.635)^2 = 0.317\ in^2$

Effective external pressure area of the tube cross section:

Area = $(0.785)\ (0.875)^2 = 0.601\ in^2$

Effective tube pressure end load:

Load = 0.317 Pi - 0.601 Po

Where: Pi = internal pressure

Po = secondary pressure

8.3.2 Primary Pressure Application

Four design pressure loading conditions are analyzed.

- Case 1 - Primary and secondary side design pressure
- Case 2 - Primary side design pressure (tube severed)
- Case 3 - Secondary side design pressure (tube severed)
- Case 4 - Primary and secondary side design pressure (tube severed)

Case 1

An internal design pressure of 2500 psi was applied to the inside surface of the sleeve and unsleeved portion of the tube. Also, a secondary side design pressure of 1100 psi was applied to the outside surface of the tube (see Figure 8-7).

Case 2

An internal design pressure of 2500 psi was applied to the inside surface of the sleeve and unsleeved portion of the tube (see Figure 8-8). The tube is in a severed condition or structurally disconnected such that the tube carries no axial loading.

Case 3

A external design pressure of 1100 psi was apied to the outside surface of the tube and in the annular region between the sleeve and tube (see Figure 8-9). The tube is in a severed condition.

Case 4

Same as 1 above except the tube is in a severed condition.

8.3.3 Normal Operating Conditions

The tube/sleeve thermal transient analysis is used in determining the fatigue life of the assembly. To find the most accurate total useful life for the normal operation conditions, usage factors from all the normal operating transients are combined.

During operation the primary fluid is in contact with the inside surface of the sleeve and unsleeved portions of the tube. The secondary side fluid is in contact with the tube external surface above the top of the tubesheet. In the event of tube leakage, the annulus between the sleeve and tube will be filled with water or steam. In order to maximize the axial thermal gradients, the thermal analysis was performed for a non-leaking tube which represents an insulating air chamber between the tube and sleeve.

Table 8-11 is a tabulation of the composite thermal transient considered. Table 8-12 is a detailed listing of the thermal transient. Table 8-13 is a tabulation of the seven thermal cases chosen for analysis. These cases produced the required stress ranges for fatigue analysis.

8.4 Finite Element Analysis Results

In order to minimize the number of stress classification lines to be used in computer program CLASS, the output for a typical FESAP run was examined to determine the maximum stressed location. No significant radial thermal gradient stresses are developed in the sleeve explosive weld area. The tubesheet responds almost instantaneously to the primary coolant temperature; therefore the outside surface of the tube/sleeve lower joint area is subjected to primary coolant temperature. Thus, it is nearly impossible to develop any significant radial thermal gradient stress in the tube/sleeve explosive weld area since the geometry is relatively thin and small and the inside and outside surfaces are subjected to primary coolant temperatures. Thus the stresses in the lower joint are due to pressure and axial thermal loading while the upper joint area experiences similar pressure and axial thermal loading plus thermal radial gradient effects associated with the temperature difference between the primary and secondary fluids.

The inspection of the FESAP output revealed the upper joint as the highest stressed location in the tube/sleeve assembly. Based on this inspection and loading discussion above only the upper joint stresses were linearized using computer code CLASS.

8.4.1 Critical Sections to be Analyzed

The sections considered in the analysis of the tube/sleeve are shown in Figure 8-10. Each section chosen is described as follows:

Stress Classification Line 1

This section is located across the tube thickness above the brazed area. This section consists of the following dimensions:

Tube
Outer Diameter = 0.885"
Thickness = 0.0495"

Stress Classification Line 2

This section is located across the tube thickness at the top of the brazed area. The cross section at this location is:

Tube
Outer Diameter = 0.885"
Thickness = 0.0495"

Stress Classification Line 3

This section is located across the tube thickness at the bottom of the brazed area. The cross section at this location is:

Tube
Outer Diameter = 0.885"
Thickness = 0.0495"

Stress Classification Line 4

This section is located across the sleeve thickness at the top of the brazed area. The cross section at this location is:

Sleeve
Outer Diameter = 0.786"
Thickness = 0.0515"; includes 0.0045" Nickel

Stress Classification Line 5

This section is located across the sleeve thickness at the bottom of the brazed area. The cross section at this location is:

Sleeve
Outer Diameter - 0.786"
Thickness = 0.0515"; includes 0.0045" Nickel

Stress Classification Line 6

This section is located across the sleeve thickness in the lower expansion shoulder area at the point of maximum sleeve expansion. The cross section at this location is:

Sleeve
Outer Diameter = 0.786"
Thickness = 0.047"; Nickel material is removed from structural model

Stress Classification Line 7

This section is located across the sleeve thickness in the lower expansion shoulder area at the start of the point of sleeve expansion. The cross section at this location is:

Sleeve
Outer Diameter = 0.735"
Thickness = 0.050"; Nickel material is removed from structural model

Braze Shear Line

This line is located axially through the brazed area. This cross section consists of the length of the braze. The following configuration applies:

Tube/Sleeve Braze
Braze Length = 0.5"; minimum
Braze Diameter = 0.777"; minimum

Weld Shear Line

This line is located axially through the lower end joint explosive weld area. The cross section at this location is:

Tube/Sleeve Weld
Weld Length = 0.5"; minimum
Weld Diameter = 0.792"; minimum

8.4.2 Primary Stress Results

8.4.2.1 Design Condition

The primary local membrane plus bending stress components and stress intensities of the sleeve and tube due to pressure at the critical sections are shown in Tables 8-14 through 8-21. Each table contains the inside and outside stresses for each line. All of the stress intensities for the seven stress lines meet the ASME Code, Section III allowables. The smallest margin appears in Stress Line 7 where S = 16.2 ksi (see Table 8-20) with an allowable stress of 34.95 ksi (1.5 S_m from Table 8-2).

8.4.2.2 Test Conditions

The primary membrane, P_m, allowable stress for pressure tests is 0.9 (yield stress) or 0.9 Sy. The P_m allowable for design pressure conditions is S_m where S_m equals 2/3 Sy per ASME Code definition for Inconel 600. The ratio of primary stress allowable increase for pressure test conditions versus design pressure conditions is:

Allowable Stress ratio increase = 0.9 Sy/0.67 Sy=1.34.

Therefore, the P_m stress allowable would not be exceeded by the specified test pressures since they are equal to the design pressure specified and the design pressure is justified in Section 8.4.2.1.

The primary local membrane plus bending stress intensity, $P_L + P_b$, allowable stress for pressure tests is 1.35 Sy while the allowable stress for design pressure conditions is 1.5 Sm. The ratio of primary stress allowable for pressure test conditions versus design pressure conditions is:

Allowable stress ratio increase =
1.35 Sy/1.5 (0.67Sy) = 1.34.

Therefore, the $P_L + P_b$ stress allowable also would not be exceeded by the specified test pressures.

8.4.2.3 Faulted Conditions

As stated in Section 8.2.3 the governing Level D condition is a postulated secondary side blowdown (MSLB). The maximum primary-to-secondary pressure differential across the tube/sleeve wall is given in the Design Criteria. For the consideration of postulated rupture of the secondary side pressure boundary, the maximum primary-to-secondary side pressure differential is given as 2500 psi. The OBE and SSE bending stresses are small at the sleeve location. The OBE and SSE stresses at the braze location in the sleeve cross section at the top of the tubesheet are 1.4 and 1.8 ksi, respectively (see section 8.5).

A steam generator feedwater line break (FLB) condition as stated in the design criteria does not develop significant cross flow forces or pressure drop due to the feedwater inlet characteristics of the recirculating steam generator.

Therefore, the MSLB condition will be the limiting condition. The criterion to be used in the evaluation of this loading condition is:

$$P_m \leq \text{smaller of } 0.7\ Su = 0.7\ (80{,}000) = 56{,}000 \text{ psi}$$
$$2.4\ Sm = 2.4\ (23{,}300) = 55{,}920 \text{ psi}$$

The above criterion applies to the faulted loading condition stress intensity limit and applies to the combined stress intensity value for all loading components that contribute to the P_m category stress value.

Level D Loading

P = 2500 PSI

F = 3400 LBS

$S = PR_i^2/\pi(R_o^2 - R_i^2)$
(Longitudinal Pressure Stress)

$S = F/\pi(R_o^2 - R_i^2)$
(Axial Load Stress)

$S = PR_i/(R_o - R_i)$
(Hoop Pressure Stress)

$S = -P/2$
(Radial Stress)

For the loadings to be analyzed the longitudinal minus radial stress intensity will result in the worst case.

$$S = (PR_i^2 + F)/ \ (R_o^2 - R_i^2) - (P/2)$$

The minimum cross section of the sleeve occurs in the explosive expansion region. (The tube is assumed to be severed and the sleeve carries all the load).

Sleeve OD = 0.788 inch
Thickness = 0.047 inch

$$S = \frac{2500\ (0.347^2) + 3400}{(0.394^2 - 0.347^2)} + \frac{2500}{2}$$

S = 35.08 ksi

8.4.3 Normal Operating Conditions Results (Level A and B)

8.4.3.1 Pressure and Thermal Stress Results

The results of the tube/sleeve assembly analysis demonstrate its ability to satisfactorily resist the cyclic loadings that the tube/sleeve assembly is expected to experience during the life of the plant as defined in the design criteria.

The stress intensities of the selected critical sections of the sleeve and tube are tabulated in Tables 8-22 through 8-36. All of the stress lines meet the ASME Code, Section III allowables. The closet margin would be for Stress Line 6 where the stress is 37.3 ksi (see Table 8-38) compared to an allowable stress of 3 S_m = 69.9 ksi.

8.4.3.2 Stress Due to 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 on the primary side. Under this condition, the tubes protruding from the top of the tubesheet will rotate from the vertical thus inducing a secondary bending stress in the tube and sleeve. This rotation depends on the boundary condition for the edges of the tubesheet. For simplicity, the edges of the tubesheet are taken as partially fixed, which will be computed as the average of the simple support and fixed boundary conditions at the edges. The equation and other variables used are:

For the fixed boundary condition:

$$\theta = r\,(a^2 - r^2)\,\Delta P \,/\, 16D$$

Where: D = Flexural rigidity for a perforated plate per Article A-8000 of the ASME Code, Section III, Appendices

ΔP = Pressure differential across tubesheet

$$\theta_{max} = a^3\,\Delta P/24\sqrt{3}\,D \quad \text{at} \quad r = a\,/\sqrt{3}$$

tubesheet variables:

$D = 6.294 \times 10^9$ in-lb $a = 60.875$ inches

$E = 5.97 \times 10^6$ psi $t = 22$ inches

$\nu = 0.398$

$\theta_{max} = 8.622 \times 10^{-7}\ P$

For the simple support boundary condition:

$$\theta = \frac{-3\Delta P\ (m^2 - 1)}{4\pi\ E\ m^2\ \ t^3}\left[\frac{r^3}{a^2} - \frac{r(3m + 1)}{m + 1}\right]$$

where: m = 1/r, and other terms are defined for the fixed boundary condition.

$$\theta = 2.713 \times 10^{-6}\,\Delta P \quad \text{at } r = a/\sqrt{3}$$

Therefore, the average pressure rotation is:

$$\theta = \left[(8.622 \times 10^{-7} + 2.713 \times 10^{-6})/2\right]\Delta P$$

$$0 = 1.788 \times 10^{-6}\Delta P$$

The maximum bending stress in the sleeve fixed at the first support plate occurs at the top of the tubesheet and is:

$$M = 4EI\theta/L$$
$$S = Mc/I$$
$$S = \frac{4\ E_{tube}\ I_{tube}\ C_{sleeve}\ \theta}{LI_{sleeve}}$$

$$S = 2.544\ \Delta P$$

Thus, maximum stress is:

LOAD CASE	P (psi)	STRESS (ksi)
1	1230	3.1
2	1469	3.7
3	952	2.4
4	1763	4.6
5	420	1.1
6	1510	3.8
7	1566	4.0
Range 1	1763	4.6
Range 2	517	1.3
Range 3	97	0.3

Notes:
1) Stress ranges 1, 2 and 3 are as described in Table 8-35.
2) These stresses will be added to the maximum primary plus secondary and cyclic stresses.
3) ΔP range is taken from Table 8-13.

8.4.4 Fatigue Analysis Results

Fatigue is a mode of failure associated with multiple stress cycles. It is measured by the summation of the damage ratios or partial usage factors suffered by the part. Corresponding to each peak stress intensity, a maximum number of allowable cycles is read from the fatigue design curve in the ASME Code. The damage ratio is the fraction of the actual number of cycles experienced to the maximum cycles allowed in the Code. Over the life of the part, the damage relationship can be taken as linear since large and small stress cycles are fairly evenly distributed. For acceptability, the total sum of the damage ratios shall be less or equal to unity.

The peak stress intensity was conservatively calculated by multiplying the total primary plus secondary stress intensity range by the largest of either the bending or the tensile stress concentration factor at each section analyzed. A conservative stress intensification factor of 5.0 was used at the tip of the braze and weld sections. Elsewhere, the value used was based on typical stress indices for a piping reducer type configuration (see footnote 14, Table ND-3681 (a)-1, ASME Code, Section III).

The following stress intensification factors were used for the stress lines analyzed.

Stress Line No.	Inside	Outside
1	1.1	1.1
2	5.0	1.0
3	5.0	1.0
4	1.0	5.0
5	1.0	5.0
6	1.1	1.1
7	1.1	1.1

8.4.4.1 Peak Stress

Peak stress intensity ranges for all stress lines analyzed are tabulated in Tables 8-37 through 8-42. The total peak stress is the stress intensification factor times the total primary plus secondary stress intensity due to pressure, thermal axial and radial gradients and seismic.

8.4.4.2 Results of Fatigue Analysis

The total usage factor for the tube/sleeve is a combination of the usage factors for each of the three groups of transients discussed in the "Thermal Transients" section. The largest total usage factor calcualted was 0.01 for Stress Line 4.

The fatigue curve (S-N curve) was taken directly from the ASME Code, Section III, Division I Appendices, Figure I-9.2. The braze utilizes the same curve since the braze meets the requirements of the ASME Code, Section IX.

8.5 Seismic

An analysis was performed utilizing the steam generator tube geometry and Design Criteria to assess the impact of a seismic event on the tube/sleeve assembly. The location of the sleeve is almost entirely within the tubesheet and contributes insignificant additional mass. Seismic stresses were calculated using applied acceleration factors. OBE seismic acceleration factors of 0.7g and 0.4g in the horizontal and vertical directions, respectively, were used utilizing a static analysis method. The maximum OBE bending stress calculated at the braze joint in the sleeve cross section was 1.4 ksi.

For SSE seismic stress, acceleration factors of 0.9g and 0.8g were used in the horizontal and vertical directions, respectively. The corresponding maximum SSE stress calculated at the braze joint in the sleeve cross section was 1.8 ksi.

The OBE bending stress is therefore almost insignficant. However, it was be added to the maximum primary stress and maximum thermal and pressure primary plus secondary stress.

8.6 Axial Test Load Calculations

8.6.1 Mechanical Integrity Testing (Tube/Sleeve Assembly)

Mechanical tests were performed on specimens which simulated a bimetallic sealable sleeve installed within a steam generator tube in the tubesheet region of the steam generator, Section 7. The specimens represen the materials and configuration of the sleeved region of the steam generator and were assembled using tooling and procedures developed for the rapid sleeving program. Five such specimens were each subjected to a sequence of six tests for the purpose of demonstrating:

1) The mechanical integrity of the sleeve design and the integrity of the upper and lower sleeve-to-tube attachment joints,

2) The capability of the upper joint braze serving as the primary-to-secondary pressure boundary, and

3) The adequacy of the rapid sleeve installation process.

The testing sequence consists of primary and secondary side hydrotests, axial fatigue testing, additional primary and secondary side hydrotests and a final tension test to failure. During operation the braze is subjected to combined transverse shear, compressive radial and hoop stress. The axial test loading imposed simulates the maximum shear stress in the braze joint during its specified service loading. The tension test determines the ability of the joints to withstand Level D (faulted) conditions at a simulated end of life condition. In addition, the test assembly is internally pressurized to approximate the primary to secondary side differential pressure.

For the base program testing, the internal pressure, peak tensile load, loading frequency and number of loading cycles for the three stages of the fatigue test are:

	Internal Pressure (psig)	Peak Load (lbs.)	Loading Frequency (cps)	Load Cycles
Stage A	1710	3035	1	200
Stage B	1550	1460	3	6500
Stage C	1550	1340	3	15000
Total Load Cycles				21700

The results of this test program are summarized and evaluated in Section 7.0 of this report.

8.6.2 Upper Joint Strength Testing

All sleeving operations involving the previous hydraulic expansion of the upper end joint, considered the expansion in combination with the braze as forming the sleeve-to-tube structural joint at the upper end of the sleeve. The expansion by itself provides a structural joint to restrain the tube/sleeve assembly in the hypothetical instance where a braze fails in service during steam generator operation.

In the rapid sleeving concept the braze may be considered as only a seal when used in conjunction with another ASME code qualified joint. A testing program wa initiated to provide an evaluation of the capability of the explosive expansion alone to carry the axial structural loads imposed on the upper joint under worst case service conditions.

The test specimens for this evaluation only represent the upper joint and are assembled using the rapid sleeving installation processes, with the exception that the sleeves do not include the braze material. However, the sleeves are exposed to a prebraze/heat treat thermal cycle.

The testing sequence consists of subjecting each specimen to elevated temperature axial fatigue testing followed by a room temperature tension test to failure. The test loading required is the upper joint axial restrain force. The test loading will not simulate the combined service stress in the expansion joint but will instead simulate the worst case service axial shear force in the upper end joint.

Each specimen will be subjected to completely reversed axial cyclic loading at 600°F for a total of 21,700 load cycles. The applied loading fluctuated sinusoidally between peak tensile and compressive loads of 1,200 pounds (zero mean load) at a frequency of 1 load cycle per second. The axial tensile loadings and cycles required are:

Tensile Load	Load Cycles
1200	21700

The testing results determine the explosive expansion joint's capability to carry the axial structural loads imposed under worst case service conditions. The results also determine if the mechanical expansion joint can be classified as the primary tube/sleeve upper end structural joint and as such the braze classified as only a seal.

8.7 Tube/Sleeve Frequency Comparison

Analytical assessments were prepred to predict natural frequencies for sleeved and unsleeved tubes. The purpose of the assessment was to evaluate the effect on the original tube's natural frequency when a 36 inch sleeve is installed. Also, complete severance of the tube, no support at the top of the tubesheet were investigated.

8.7.1 Method of Analysis

The finite element model of the U-tube and the sleeve was used to calculate natural frequencies. Horizontal simple constraints were used to represent the six support plates. A number of points were constrained in the tubesheet thickness to model the potential of lateral support of the tube. The computer code, ANSYS was used and the model has 50 elastic 3-D pipe elements. The tube is fixed in all directions at the lower tubesheet region to represent the explosive weld.

A second set of boundary conditions was modeled to evaluate the effect of a crevice or gap through the tubesheet which does not provide lateral support for the tube. Table 8-43 presents the results for these two tube boundary conditions.

The model was varied to define three separate models for comparison purposes. First the original tube is modeled by removing the sleeve portion of the model, then the full model containing the sleeve is evaluated. The third model is defined by structurally disconnecting the tube below the upper surface of the tubesheet. The boundary conditions which provide no horizontal support at the top of the tubesheet and model 3 represent a case of tube severance near the tubesheet upper surface.

Flow velocities perpendicular to the tubes have been calculated using the ATHOS computer code. The predicted velocity distribution in the outer periphery is approximately 2.5 ft/sec and the interior region where sleeving can be performed is approximately 1.3 ft/sec. If these flow velocities are approximated as 2 ft/sec then a vortex shedding frequency of 8.5 Hertz is predicted for the tube bank.

8.7.2 Conclusions and Summary of Results

The results of the frequency calculations for the generalized set of boundary conditions (Set 1) show the addition of a sleeve in a steam generator produces an insignificant frequency shift from the original tube frequency (see Table 8-43). The calculated natural frequency of an original tube and a sleeved tube is 30.26 and 30.33 hertz, respectively. The natural frequency of a sleeved tube where the tube is severed below the top of the tubesheet (the tube retains horizontal restraint) has a frequency of 29.08 hertz. These frequency comparisons show only a small separation (3.9%) which is acceptable in the regions of the steam generator where sleeving is occurring. A sleeved tube natural frequency is higher than the original tube, thus demonstrating the reinforcement the sleeve provides.

The natural frequencies in Table 8-43 are above the vortex shedding frequency prediction (8.5 hertz). This frequency ratio provides satisfactory assurance that no high amplitude flow induced vibrations can occur. The case of a severed tube at the top of the tubesheet (21.15 hertz) is sufficiently above the vortex shedding frequency to preclude concern. This case is beyond the boundary of the design criteria which states that crevice cracking occurs below the top of the tubesheet. The natural frequency for model 1, boundary condition 2, of 25.29 hertz is the lowest structural frequency to be considered for potential of flow induced vibrations. Note that this case is for the original tube prior to sleeving.

The sleeving of the tube for boundary conditions 1 and 2 increase the natural frequency of the tube/sleeve combination and expected tube severance does not degrade the structural frequencies.

8.8 Thermal/Hydraulic Analysis

An analysis was performed to determine the effect of total hot leg steam generator sleeving on the thermal hydraulic performance of the RG&E Steam Generator. For sleeves installed in all steam generator hot leg tubes, the primary side pressure drop is expected to increase by approximately 3 psi or approximately 7 percent over that of an unsleeved generator. With this additional 3 psi pressure drop across the steam generator, the effect on the total primary system pressure drop is approximately 3 percent. Considering this increase, the effect on the reactor coolant system pump flow is negligible. A pressure drop of approximately 7 percent corresponds to plugging approximately 3.3 percent of the generator tubes assuming the plugs are randomly distributed. Also, no adverse effects due to cavitation/erosion are expected to occur due to sleeving of tubes in the steam generator.

Calculations were prepared to determine the heat transfer decrease due to total steam generator hot leg sleeving. The sleeve and tube are separated by an air gap which functions as a insulating medium. Thus, based on negligible heat transfer along the sleeved tube length, the total heat transfer decrease is approxiamtely 2 percent.

8.9 Plugging Criteria

The present base ISI Program requires plugging of any steam generator tube with a defect indication of 40% or greater through wall. This was based on the possibility of cracking occurring on tubes with previous wastage on the tube outside diameter above the tubesheet. Prior to that, a 50% plugging criteria had been used based on occurrence of a single phenomena such as wastage. For a single failure phonemena within the tubesheet, such as intergranular attack, a 50% tube plugging criteria is appropriate. To determine an appropriate plugging criteria for sleeves, calculations were performed comparing a sleeve with a tube having 50% wastage on the tube. The results of these calculations are as follows:

Table 8-44
TUBE AND SLEEVE STRENGTH COMPARISONS

	Original Tube	Original Tube with 50% wastage on Tube OD	Sleeve
Thickness, t	0.050	0.025	0.050[1]
Outside Diameter D_o	0.875	0.825	0.735[1]
Inside Diameter D_i	0.775	0.775	0.635[1]
Hoop Stress Parameters (Di + 2t)/2t	8.75	16.50	7.35
Axial Stress Parameters (Di + 2t)/4t	4.38	8.25	3.68
Bending Stress Parameter (Di + 2t)/2I	39.54	81.98	57.92

NOTE 1: Dimensions are nominals and correspond to Inconel base metal only. Sleeve has a nominal OD of 0.745 inch containing a maximum of 0.009 inch nickel.

From Table 8-44 the following equivalent sleeve thicknesses can be calculated using the parameters for a 50% wastage tube:

Sleeve thickness required due to internal pressure -

$16.50 = (Di + 2t)/2t$ $\quad\quad\quad$ $t = 0.021$ inch

Sleeve thickness required for equivalent bending strength -

$81.98 = (Di + 2t)/2I$ $\quad\quad\quad$ $t = 0.037$ inch

The bending strength parameter is the limiting value. A sleeve thickness of 0.037 inch corresponds to a 32% reduction in the total sleeve wall (nominal sleeve wall thickness = 0.055 inch).

However, if the sleeve plugging criteria is based on faulted condition stress allowables, a 42% sleeve plugging limit can be utilized. This limit is based on a main steam line break (MSLB) condition. The criterion used in the evaluation of the minimum wall thickness is Level D stress allowable requirements of the ASME Code, Section III. Using a maximum primary to secondary pressure differential of 2500 psi and an axial loading requirement of 3400 lbs per tube, the minimum sleeve thickness required is 0.032 inches as calculated below. This calculation assumes the tube is in a severed condition (sleeve carries all axial loads).

From Section 8.4.2.2 the total Level D condition allowable stress is 55920 psi. The sleeve axial stress is calculated using:

$$S = (PR_i^2 + F)/\pi(R_0^2 - R_i^2) - (-P/2)$$

Thus, solving for R_0

$$R_0^2 = \frac{R_i^2 \left[P + \pi(55920) - 0.5\pi P\right] + F}{\pi(55920 - 0.5P)}$$

To maximize the thickness required use the inside diameter equal to 0.635 inches. Then;

$$R_o \geq 0.3494"$$

the minimum thickness required equals 0.3494 - 0.3175 = 0.0319 inches. Use 0.032 inches as the minimum required thickness. The 0.032 inch requirement corresponds to a sleeve plugging requirement of 42% wall degradation (0.055 inch nominal sleeve wall).

The above comparisons demonstrate that for a sleeve plugging criteria based on the equivalent bending strength, a 32% sleeve wall (0.055 inch nominal sleeve wall) degradation is a conservative limit. Since significant cross flow forces are not developed during a Level D condition in the recirculating steam generator a sleeve plugging criteria based on axial loading limits would be acceptable. Thus, a sleeve plugging limit of 42% should be considered as applicable.

Table 8-1

TYPICAL DIMENSIONS FOR RG&E TUBE, SLEEVE AND TUBESHEET

	(Inches)
HEIGHT	
Sleeve	36.0
GAP	
Sleeve - Tube	0.015
Tube - Tubesheet	0.008
CLADDING	
Inconel Cladding on Bottom of Tubesheet	0.250
TUBE	
ID (Nominal)	0.775
OD (Nominal)	0.875
SLEEVE	
ID (nominal)	0.635
OD (nominal)	0.745
Nickel Thickness (nominal)	0.005
TUBESHEET	
Hole ID (nominal)	0.890
Thickness	22.0
EXPLOSIVE EXPANSION	
Length	2.0
TUBE ROLL EXPANSION	
Length	2.75
BRAZE JOINT	
Length (minimum)	0.50
WELD JOINT	
Length (minimum)	0.50

PROPRIETARY

Table 8-2

STRESS ALLOWABLES FOR SLEEVE

(Sleeve material is Inconel 600)

TEMPERATURE °F	DESIGN STRESS INTENSITY S_m, ksi	YIELD STRENGTH Sy, ksi	ULTIMATE STRENGTH Su, 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

Table 8-3

STRESS ALLOWABLES FOR TUBE

(Tube material is Inconel 600)

TEMPERATURE °F	DESIGN STRESS INTENSITY S_m, ksi	YIELD STRENGTH Sy, ksi	ULTIMATE STRENGTH Su, 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

Note: Stress values taken from the 1980 Edition of the ASME Code, Section III.

Table 8-4

DESIGN, FAULTED AND TEST CONDITIONS

CONDITIONS	REFERENCE	SLEEVE PRESSURE LOADING PRIMARY (PSIG)	SLEEVE PRESSURE LOADING SECONDARY (PSIG)
Design	Design Criteria	2485	1085
Faulted (MSLB)	Design Criteria	2500	0
Faulted (LOCA)	Design Criteria	0	1100
Test	Design Criteria	2485	0
1.10 (2235)	Section XI/IWB-5222	2459	0
Test	Design Criteria	0	1085
1.25 (Maximum secondary setpoint)	Section XI/IWC-5222	0	-

PROPRIETARY

Table 8-5

PRESSURE TRANSIENTS

PRESSURE TRANSIENT	PRIMARY SIDE PRESSURE (PSIG)	SECONDARY SIDE PRESSURE (PSIG)	REQUIRED CYCLES
1. Plant heatup & cooldown			200
initial	0	0	
final	2235	1005	
2. Plant loading & Plant unloading			14500
initial	2235	1005	
final	2235	776	
3. Reactor Trip			400
t = 0	2235	766	
t = 10 sec.	2200	972	
t = 15 sec.	2160	980	
t = 25 sec.	2080	964	
t = 35 sec.	1985	948	
t = 60 sec.	1900	940	
t = 90 sec.	1935	1005	
4. Loss of Load			80
t = 0 sec.	2235	766	
t = 4 sec.	2600	870	
t = 7.5 sec.	2760	946	
t = 15 sec.	2760	1137	
t = 40 sec.	1860	1137	
t = 80 sec.	1625	1137	
t = 180 sec.	1425	1005	
5. Loss of Flow			80
t = 0	2235	766	
t = 1 sec.	NA	766	
t = 4 sec.	NA	972	
t = 15 sec.	NA	940	
6. Step Load - +10%			2000
a. Increase - maximum	2274	780	
minimum	2130	697	
b. Decrease - maximum	2310	890	
minimum	2135	780	
7. Step Reduction (100% to 60%)			200
t = 0	2235	766	
t = 2 min.	2375	841	
t = 4 min.	2310	856	
t = 16 min.	2245	850	

PROPRIETARY

Table 8-6
SELECTED PRESSURE TRANSIENT GROUPS

Case	Description	Primary P (PSIG)	Secondary P (PSIG)	Required Cycles
1	Heatup & Cooldown	2235	1005	200
2	Loading & Unloading	0	239	14500
3	Step Load, Reactor Trip, Loss of Flow	335	239	6960
4	Loss of Load	1335	371	80
5	Test (Primary)	2485	0	55
6	Test (Secondary)	0	1085	55

PROPRIETARY

TABLE 8-7

RG&E PRIMARY FLUID THERMAL TRANSIENTS

Thermal Transient	Time (Min.)	Temperature (°F)	Gradient (°F/HR)
1. Plant Heat-up and Cool-down	0.0	100.0	-
	268.2	547.0	100
2. Plant Loading & Unloading	0.0	547.0	-
	20.0	605.4	175
3. Reactor Trip	0.0	605.4	-
	0.25	580.0	6096
	0.58	564.3	2855
	0.67	560	2867
	1.0	550	1818
	1.5	547	360
4. Loss-of-Load	0.0	605.4	-
	0.12	660	27300
	0.18	662	2040
	0.25	660	1714
	0.83	590	7238
	1.67	560	2135
	3.0	547.0	586
5. Loss-of-Flow	0.0	605.4	-
	0.05	612.0	7920
	0.30	546.0	15857
	0.40	547.0	600
6. Step Load + 10%			
a. Increase	0.0	599.0	-
	1.0	593.0	360
	1.5	593.0	0
	5.0	618.0	426
b. Decrease	0.0	605.4	-
	1.25	612.0	320
	1.67	612.0	0
	4.0	592.0	515
	5.0	590.0	120

PROPRIETARY

TABLE 8-7

RG&E PRIMARY FLUID THERMAL TRANSIENTS (Continued)

Thermal Transient	Time (Min.)	Temperature (°F)	Gradient (°F/HR)
7. Step Load Reduction (100% to 60%)	0.0	612.0	-
	2.0	627.0	450
	4.0	627.0	0
	10.0	595.0	320
	16.0	577.0	180

PROPRIETARY

TABLE 8-8

RG&E SECONDARY FLUID THERMAL TRANSIENTS

Thermal Transient	Time (Min.)	Temperature (°F)	Gradient (°F/HR)
1. Plant Heat-up and Cool-down	0.0	100.0	100
	268.2	547.0	100
2. Plant Loading & Unloading	0.0	547.0	-
	20.0	515.4	95
3. Reactor Trip	0.0	515.4	-
	0.08	540.0	18450
	0.25	545	1800
	0.67	540	552
	1.0	540	0
	1.5	547	840
4. Loss-of-Load	0.0	515.4	-
	0.18	562.0	15545
	3.0	547	319
5. Loss-of-Flow	0.0	515.4	-
	0.03	536.0	41200
	0.07	543.0	10500
	0.17	540.0	1800
	0.43	538.0	462
6. Step Load - + 10%			
a. Increase	0.0	517.5	-
	1.0	505.0	750
	1.67	505.0	0
	4.0	513.0	206
	5.0	513.0	0
b. Decrease	0.0	517.5	-
	0.58	530.0	1293
	1.17	532.5	254
	4.0	526.0	138
	5.0	526.0	0

PROPRIETARY

TABLE 8-8

RG&E SECONDARY FLUID THERMAL TRANSIENTS (Continued)

Thermal Transient	Time (Min.)	Temperature (°F)	Gradient (°F/HR)
7. Step Load Reduction (100% to 60%)	0.0	515.4	-
	2.0	525	288
	4.0	530	150
	10.0	529	10
	16.0	529	0

PROPRIETARY

Table 8-9

THERMAL TRANSIENTS FOR THE STEAM GENERATOR

	Thermal Transient	Temperature Range (°F)	t (°F)	Maximum Gradient (°F/Hr)	Cycles
1.	Plant Heatup & Cooldown	100 - 547	447	100	200
2.	Plant Loading & Unloading				
	Primary Side	547 - 605	58	174	14500
	Secondary Side	547 - 515	32	96	
3.	Reactor Trip				400
	Primary Side	605 - 547	58	6096	
	Secondary Side	515 - 547	32	18450	
4.	Loss-of-Load				80
	Primary Side	662 - 560	102	27300	
	Secondary Side	515 - 562	47	15545	
5.	Loss-of-Flow				80
	Primary Side	612 - 547	66	15857	
	Secondary Side	515 - 543	28	41200	
6.	Step Load - 5%	597 - 568	29	682	2000
7.	Step Load - 10%	614 - 593	24	252	2000
8.	Step Load - 20%	594 - 564	30	432	2000
9.	Step Load Decrease - 40%	627 - 577	50	235	200
10.	Step Load Decrease - 50%	589 - 550	39	234	200
11.	Step Load Decrease - 95%	594 - 550	44	240	80

PROPRIETARY

Table 8-10
SELECTED THERMAL TRANSIENTS

TRANSIENT	CASE NO.	REQUIRED CYCLES
1. Plant Heatup & Cooldown	1	200
2. Plant Loading & Unloading	2	14500
3. Reactor Trip (Includes Loss-of-Flow)	3	480
4. Loss-of-Load	4	80
5. Step Load ($\pm$5, $\pm$10 & $\pm$20%)	5	6000
6. Step Load Reduction (100 to 60, 100 to 5, and 50 to 0%)	6	480

PROPRIETARY

Table 8-11

TRANSIENT DESCRIPTION

Time (minutes)	Description
0.0 to 268.2	Heatup from 100°F to 0% power
268.2 to 280	0% Power hold
280 to 300	Power loading 0% to 100%
300 to 310	100% power hold
310 to 330	Power unloading 100% to 0%
330 to 340	0% power hold
340 to 350	Step change to 100% power with hold
350 to 351.5	Reactor trip from 100% power
351.5 to 360	0% power hold
360 to 370	Step change to 100% power with hold
370 to 373	Loss of load from 100% power
373 to 380	0% power hold
380 to 390	Step change to 100% power with hold
390 to 395	Step load decrease 10% of full power
395 to 400	Step change to 90% power with hold
400 to 405	Step load increase 10% of full power
405 to 410	Step change to 100% full load with hold
410 to 425	Step reduction from 100% to 60% load
425 to 430	Step change to 50% load with hold
430 to 445	Step reduction from 50% to 0% load
445 to 455	Step change to 100% load with hold
455 to 470	Step reduction from 100% to 5% load
470 to 480	Step change 0% power with hold
480 to 748.2	Cooldown from 0% power to 100°F

Table 8-12

DETAILED TRANSIENT DESCRIPTION

Time (min)	Fluid Temperature Primary (°F)	Fluid Temperature Secondary (°F)	Time (min)	Fluid Temperature Primary (°F)	Fluid Temperature Secondary (°F)
0.0	100.0	100.0	394.0	592.0	526.0
120.0	300.0	300.0	395.0	590.0	525.0
240.0	500.0	500.0	395.0	599.0	518.0
268.2	547.0	547.0	400.0	599.0	518.0
275.0	547.0	547.0	401.0	593.0	505.0
280.0	547.0	547.0	401.5	593.0	505.0
300.0	605.4	515.4	404.0	610.9	513.0
310.0	605.4	515.4	405.0	618.0	513.0
330.0	547.0	547.0	405.0	612.0	515.4
340.0	547.0	547.0	410.0	612.0	515.4
340.0	605.4	515.4	412.0	627.0	525.0
350.0	605.4	515.4	414.0	627.0	530.0
350.08	597.0	540.0	420.0	595.0	529.0
350.25	580.0	545.0	425.0	580.0	529.0
350.67	560.0	540.0	425.0	576.0	529.0
351.0	550.0	540.0	430.0	576.0	529.0
351.5	547.0	547.0	432.0	589.0	540.0
360.0	547.0	547.0	434.0	589.0	545.0
360.0	605.4	515.4	440.0	555.0	549.0
370.0	605.4	515.4	445.0	550.0	547.0
370.12	660.0	539.7	445.0	575.0	529.0
370.18	662.0	562.0	455.0	575.0	529.0
370.25	660.0	562.0	456.0	595.0	542.0
370.83	590.0	562.0	457.0	595.0	540.0
371.67	560.0	562.0	463.0	568.0	549.0
373.0	547.0	547.0	467.0	550.0	545.0
380.0	547.0	547.0	470.0	555.0	535.0
380.0	605.4	515.4	470.0	547.0	547.0
390.0	605.4	515.4	480.0	547.0	547.0
390.8	609.6	532.0	508.2	500.0	500.0
391.25	612.0	532.0	628.2	300.0	300.0
391.67	612.0	532.0	748.2	100.0	100.0

PROPRIETARY

Table 8-13

SELECTED LOAD CASES FOR ANALYSIS

Load Case	Time (min)	T_p (°F)	T_s (°F)	P_p (Psig)	P_s (Psig)	Transient Description
1	275.00	547	547	2235	1005	0% Power
2	304.00	605.4	515.4	2235	766	100% Power
3	350.80	556	540	1900	948	End of reactor trip
4	370.12	660	546	2760	997	Loss of Load
5	373.00	547	547	1425	1005	End of Loss of Load
6	404.80	616	513	2260	750	End of 10% Step Increase
7	412.00	627	525	2400	834	Step Load Reduction from 100% to 60% Load

Where: T_p = Primary fluid temperature
T_s = Secondary fluid temperature
P_p = Primary side pressure
P_s = Secondary side pressure

PROPRIETARY

Table 8-14

PRIMARY STRESS INTENSITY RANGE

STRESS LINE-1

LOAD CASE	INSIDE RAD	INSIDE LONG	INSIDE HOOP	INSIDE R-L	INSIDE L-H	INSIDE H-R
1	0.2	8.0	6.6	-7.8	1.4	6.4
2	2.3	16.2	13.7	-13.9	2.5	11.4
3	-2.1	-8.2	-7.1	6.1	-1.1	-5.0
4	0.2	8.0	6.6	-7.8	1.4	6.4
Maximum				13.9	2.5	11.4

LOAD CASE	OUTSIDE RAD	OUTSIDE LONG	OUTSIDE HOOP	OUTSIDE R-L	OUTSIDE L-H	OUTSIDE H-R
1	-1.0	0.1	3.0	-1.1	-2.9	4.0
2	0.1	2.1	7.4	-2.0	-5.3	7.3
3	-1.0	-2.0	-4.3	0.9	2.3	-3.2
4	-1.0	0.1	3.0	-1.1	-2.9	4.0
Maximum				2.0	5.3	7.3

NOTES: 1) All stresses are in KSI

2) Maximum is defined as the largest absolute value from load cases 1 through 4.

PROPRIETARY

Table 8-15

PRIMARY STRESS INTENSITY RANGE

STRESS LINE-2

LOAD		INSIDE			INSIDE	
CASE	RAD	LOND	HOOP	R-L	L-H	H-R
1	-1.1	3.1	3.2	-4.2	-0.1	4.3
2	0.1	8.4	8.6	-8.3	-0.2	8.5
3	-1.3	-6.6	-6.7	5.3	0.1	-5.4
4	-1.1	3.1	3.2	-4.2	-0.1	4.3
Maximum				8.3	0.2	8.5

LOAD		INSIDE			OUTSIDE	
CASE	RAD	LONG	HOOP	R-L	L-H	H-R
1	-1.2	3.4	4.1	-4.6	-0.7	5.3
2	0.1	7.5	8.7	-7.6	-1.2	8.8
3	-1.1	-3.3	-3.8	2.2	0.5	-2.7
4	-1.2	3.4	4.1	-4.6	-0.7	5.3
Maximum				7.6	1.2	8.8

NOTES: 1) All stresses are in KSI

2) Maximum is defined as the largest absolute value from load cases 1 through 4.

PROPRIETARY

Table 8-16

PRIMARY STRESS INTENSITY RANGE

STRESS LINE-3

LOAD CASE	INSIDE RAD	INSIDE LONG	INSIDE HOOP	INSIDE R-L	INSIDE L-H	INSIDE H-R
1	-2.5	-0.1	2.3	-2.4	-2.4	4.8
2	-1.4	2.4	7.1	-3.8	-4.7	8.5
3	-0.7	-3.8	-6.0	3.1	2.2	-5.3
4	-2.0	-0.2	2.3	-1.8	-2.5	4.3
Maximum				3.8	4.7	8.5

LOAD CASE	INSIDE RAD	INSIDE LONG	INSIDE HOOP	OUTSIDE R-L	OUTSIDE L-H	OUTSIDE H-R
1	-1.2	1.8	3.9	-3.0	-2.1	5.1
2	-0.1	4.3	8.3	-4.4	-4.0	8.4
3	-1.0	-1.9	-3.6	0.9	1.7	-2.6
4	-1.2	1.7	3.9	-2.9	2.2	5.1
Maximum				4.4	4.0	8.4

NOTES: 1) All stresses are in KSI

2) Maximum is defied as the largest absolute value from load cases 1 through 4.

PROPRIETARY

Table 8-17

PRIMARY STRESS INTENSITY RANGE

STRESS LINE-4

LOAD CASE	INSIDE RAD	INSIDE LONG	INSIDE HOOP	INSIDE R-L	INSIDE L-H	INSIDE H-R
1	-2.4	-0.2	4.2	-2.2	-4.4	6.6
2	-2.3	1.0	8.8	-3.3	-7.8	11.1
3	-0.1	-0.4	-3.9	0.3	3.5	-3.8
4	-2.4	-0.2	4.2	-2.2	-4.4	6.6
Maximum				3.3	7.8	11.1

LOAD CASE	OUTSIDE RAD	OUTSIDE LONG	OUTSIDE HOOP	OUTSIDE R-L	OUTSIDE L-H	OUTSIDE H-R
1	-1.9	-3.9	0.9	2.0	-4.8	2.8
2	-1.3	-4.0	4.6	2.7	-8.6	5.9
3	-0.7	-1.1	-5.0	0.4	3.9	-4.3
4	-1.9	-3.9	0.9	2.0	-4.8	2.8
Maximum				2.7	8.6	5.9

NOTES: 1) All stresses are in KSI

2) Maximum is defined as the largest absolute value from load cases 1 through 4.

Table 8-18

PRIMARY STRESS INTENSITY RANGE

STRESS LINE-5

LOAD CASE	INSIDE RAD	INSIDE LONG	INSIDE HOOP	INSIDE R-L	INSIDE L-H	INSIDE H-R
1	-2.3	2.0	5.3	-4.3	-3.3	7.6
2	-2.2	5.1	10.9	-7.3	-5.8	13.1
3	-0.1	-2.3	-4.9	2.2	2.6	-4.8
4	-2.3	2.0	5.3	-4.3	-3.3	7.6
Maximum				7.3	5.8	13.1

LOAD CASE	OUTSIDE RAD	OUTSIDE LONG	OUTSIDE HOOP	OUTSIDE R-L	OUTSIDE L-H	OUTSIDE H-R
1	-2.5	-0.3	2.3	-2.2	-2.6	4.8
2	-1.5	2.8	7.3	-4.3	-4.5	8.8
3	-0.6	-4.2	-6.2	3.6	2.0	-5.6
4	-2.0	-0.2	2.4	-1.8	-2.6	4.4
Maximum				4.3	4.5	8.8

NOTES: 1) All stresses are in KSI

2) Maximum is defined as the largest absolute value from load cases 1 through 4.

Table 8-19

PRIMARY STRESS INTENSITY RANGE

STRESS LINE-6

LOAD CASE	INSIDE RAD	INSIDE LONG	INSIDE HOOP	INSIDE R-L	INSIDE L-H	INSIDE H-R
1	-10.8	-5.4	-0.8	-5.4	-4.6	10.0
2	-3.9	0.5	5.5	-4.4	-5.0	9.4
3	1.9	-1.2	-3.3	3.1	2.1	-5.2
4	-2.8	-0.8	2.1	-2.0	-2.9	4.9
Maximum				5.4	5.0	10.0

LOAD CASE	OUTSIDE RAD	OUTSIDE LONG	OUTSIDE HOOP	OUTSIDE R-L	OUTSIDE L-H	OUTSIDE H-R
1	-1.5	7.9	4.5	-9.4	3.4	6.0
2	-0.3	4.7	6.6	-5.0	-1.9	6.9
3	-1.0	-2.3	-3.6	1.3	1.3	-2.6
4	-1.3	2.4	2.9	-3.7	-0.5	4.2
Maximum				9.4	3.4	6.9

NOTES: 1) All stresses are in KSI

2) Maximum is defined as the largest absolute value from load cases 1 through 4.

Table 8-20

PRIMARY STRESS INTENSITY RANGE

STRESS LINE-7

LOAD CASE	INSIDE RAD	INSIDE LONG	INSIDE HOOP	INSIDE R-L	INSIDE L-H	INSIDE H-R
1	-2.5	-1.4	7.8	-1.1	-9.2	10.3
2	-2.3	-0.7	12.7	-1.6	-13.4	15.0
3	-0.1	-0.7	-7.0	0.6	6.3	-6.9
4	-2.4	-1.4	5.7	-1.0	-7.1	8.1
Maximum				1.6	13.4	15.0

LOAD CASE	OUTSIDE RAD	OUTSIDE LONG	OUTSIDE HOOP	OUTSIDE R-L	OUTSIDE L-H	OUTSIDE H-R
1	-0.4	3.2	8.9	-3.6	-5.7	9.3
2	0.1	15.2	16.3	-15.1	-1.1	16.2
3	-1.3	-10.4	-9.3	9.1	-1.1	-8.0
4	-1.1	4.8	7.0	-5.9	-2.2	8.1
Maximum				15.1	5.7	16.2

NOTES: 1) All stresses are in KSI

2) Maximum is defined as the largest absolute value from load cases 1 through 4.

PROPRIETARY

Table 8-21

PRIMARY AXIAL LOADING

LOAD CASE	SLEEVE (LBS)	TUBE (LBS)
1	94	69
2	817	0
3	-622	0
4	201	0

PRIMARY AXIAL LOADING AVERAGE SHEAR STRESS

LOAD CASE	BRAZE (ksi)	WELD (ksi)	ALLOWABLE STRESS (ksi)
1	0.2	0.2	7.0
2	1.3	1.3	7.0
3	1.0	1.0	7.0
4	0.3	0.3	7.0

Notes: 1) Average shear stress was calculated using a required fabrication minimum weld or braze length of 0.25 inches as per the intent of the ASME Code, Section XI.

2) Allowable stress was calculated by multiplying the Code allowble shear stress of 0.6 S_m by a quality factor of 0.5.

PROPRIETARY

Table 8-22

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-1

CASE	INSIDE			INSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	0.1	6.8	5.6	-6.7	1.2	5.5
2	-3.3	1.1	10.6	-4.4	-9.5	13.9
3	-0.7	3.9	4.7	-4.6	-0.8	5.4
4	-4.8	0.5	14.5	-5.3	-14.0	19.3
5	-0.7	1.6	1.2	-2.3	0.4	1.9
6	-3.9	0.2	11.4	-4.1	-11.2	15.3
7	-3.8	0.6	11.6	-4.4	-11.0	15.4
RANGE 1	-	-	-	6.7	15.2	19.3
RANGE 2	-	-	-	2.3	10.7	8.5
RANGE 3	-	-	-	0.3	1.7	1.5

Notes:
1) All stresses are in KSI
2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.
3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.
4) Stress intensity range 3 is defined by load cases 2, 6, and 7.
5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-23

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-1

CASE	OUTSIDE			OUTSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-1.0	0.0	2.6	-1.0	-2.6	3.6
2	-1.2	8.3	14.7	-9.5	-6.4	15.9
3	-1.0	1.1	3.5	-2.1	-2.4	4.5
4	-1.5	12.0	20.8	-13.5	-8.8	22.3
5	-1.0	-0.7	0.2	-0.3	-0.9	1.2
6	-1.2	9.5	16.5	-10.7	-7.0	17.7
7	-1.3	9.4	16.5	-10.7	-7.1	17.8
RANGE 1	-	-	-	13.5	8.8	22.3
RANGE 2	-	-	-	8.5	4.0	12.3
RANGE 3	-	-	-	1.2	0.7	1.9

Notes:
1) All stresses are in KSI
2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.
3) Stress intensity 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.
4) Stress intensity range 3 is defined by load cases 2, 6, and 7.
5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-24

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-2

CASE	INSIDE			INSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-1.0	2.9	2.9	-3.9	0.0	3.9
2	-2.3	-1.2	5.0	-1.1	-6.2	7.3
3	-1.2	1.2	2.0	-2.4	-0.8	3.2
4	-3.0	-1.7	7.1	-1.3	-8.8	10.1
5	-1.0	0.0	0.0	-1.0	0.0	1.0
6	-2.5	-1.8	5.3	-0.7	-7.1	7.8
7	-2.6	-1.6	5.4	-1.0	-7.0	8.0
RANGE 1	-	-	-	3.9	8.8	10.1
RANGE 2	-	-	-	2.8	6.2	4.1
RANGE 3	-	-	-	0.4	0.9	0.7

Notes:
1) All stresses are in KSI

2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.

3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.

4) Stress intensity range 3 is defined by load cases 2, 6, and 7.

5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-25

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-2

CASE	OUTSIDE			OUTSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-1.1	2.8	3.3	-3.9	-0.5	4.4
2	-1.1	10.3	15.4	-11.4	-5.1	16.5
3	-1.0	3.0	4.0	-4.0	-1.0	5.0
4	-1.3	14.1	21.3	-15.4	-7.2	22.6
5	-1.0	0.4	0.6	-1.4	-0.2	1.6
6	-1.1	11.4	17.1	-12.5	-5.7	18.2
7	-1.2	11.4	17.1	-12.6	-5.7	18.3
RANGE 1	-	-	-	15.4	7.2	22.6
RANGE 2	-	-	-	7.5	4.6	12.1
RANGE 3	-	-	-	1.2	0.6	1.8

Notes:

1) All stresses are in KSI

2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.

3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.

4) Stress intensity range 3 is defined by load cases 2, 6, and 7.

5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-26

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-3

CASE	INSIDE			INSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-2.2	-0.6	2.0	-1.6	-2.6	4.2
2	-3.2	-0.1	5.1	-3.1	-5.2	8.3
3	-2.2	-0.7	1.5	-1.5	-2.2	3.7
4	-4.1	0.5	7.4	-4.6	-6.9	11.5
5	-1.8	-1.4	-0.4	-0.4	-1.0	1.4
6	-3.4	-0.1	5.5	-3.3	-5.6	8.9
7	-3.6	-0.1	5.5	-3.5	-5.6	9.1
RANGE 1	-	-	-	4.6	6.9	11.5
RANGE 2	-	-	-	1.6	3.0	4.6
RANGE 3	-	-	-	0.4	0.4	0.8

Notes: 1) All stresses are in KSI

2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.

3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.

4) Stress intensity range 3 is defined by load cases 2, 6, and 7.

5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-27

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-3

CASE	OUTSIDE			OUTSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-1.1	1.0	3.2	-2.1	-2.2	4.3
2	-1.1	11.0	15.5	-12.1	-4.5	16.6
3	-1.0	2.0	3.9	-3.0	-1.9	4.9
4	-1.3	15.5	21.5	-16.8	-6.0	22.8
5	-1.0	-0.3	0.5	-0.7	-0.8	1.5
6	-1.1	12.5	17.2	-13.6	-4.7	18.3
7	-1.2	12.4	17.2	-13.6	-4.8	18.4
RANGE 1	-	-	-	16.8	6.0	22.8
RANGE 2	-	-	-	10.0	2.6	12.3
RANGE 3	-	-	-	1.5	0.3	1.8

Notes:
1) All stresses are in KSI

2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.

3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.

4) Stress intensity range 3 is defined by load cases 2, 6, and 7.

5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-28

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-4

CASE	INSIDE			INSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-2.1	-0.4	3.4	-1.7	-3.8	5.5
2	-2.3	-7.6	-6.2	5.3	-1.4	-3.9
3	-1.9	-1.3	1.2	-0.6	-2.5	3.1
4	-2.9	-10.9	-9.5	8.0	-1.4	-6.6
5	-1.4	-0.7	0.6	-0.7	-1.3	2.0
6	-2.4	-8.7	-7.6	6.3	-1.1	-5.2
7	-2.5	-8.7	-7.4	6.2	-1.3	-4.9
RANGE 1	-	-	-	9.7	3.8	12.1
RANGE 2	-	-	-	7.0	2.4	9.4
RANGE 3	-	-	-	1.0	0.3	1.3

Notes:
1) All stresses are in KSI

2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.

3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.

4) Stress intensity range 3 is defined by load cases 2, 6, and 7.

5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-29

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-4

CASE	OUTSIDE			OUTSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-1.7	-3.1	1.0	1.4	-4.1	2.7
2	-1.9	1.9	3.1	-3.8	-1.2	5.0
3	-1.5	-2.2	0.6	0.7	-2.8	2.1
4	-2.4	3.5	4.6	-5.9	-1.1	7.0
5	-1.3	-2.0	-0.6	0.7	-1.4	0.7
6	-2.0	2.6	3.4	-4.6	-0.8	5.4
7	-2.1	2.3	3.4	-4.4	-1.1	5.5
RANGE 1	-	-	-	7.3	4.1	7.0
RANGE 2	-	-	-	5.2	2.9	2.9
RANGE 3	-	-	-	0.8	0.4	0.5

Notes:
1) All stresses are in KSI

2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.

3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.

4) Stress intensity range 3 is defined by load cases 2, 6, and 7.

5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-30

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-5

CASE	INSIDE			INSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-2.1	2.0	4.6	-4.1	-2.6	6.7
2	-2.3	-8.4	-6.6	6.1	-1.8	-4.3
3	-1.8	0.0	1.9	-1.8	-1.9	3.7
4	-2.9	-12.5	-10.4	9.6	-2.1	-7.5
5	-1.4	0.3	1.1	-1.7	-0.8	2.5
6	-2.4	-9.9	-8.3	7.5	-1.6	-5.9
7	-2.5	-9.7	-7.9	7.2	-1.8	-5.4
RANGE 1	-	-	-	13.7	2.6	14.2
RANGE 2	-	-	-	10.2	0.8	11.0
RANGE 3	-	-	-	1.4	0.2	1.6

Notes: 1) All stresses are in KSI

2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.

3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.

4) Stress intensity range 3 is defined by load cases 2, 6, and 7.

5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY.

Table 8-31

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-5

CASE	OUTSIDE			OUTSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-2.1	0.7	2.5	-2.8	-1.8	4.6
2	-3.1	0.5	2.3	-3.6	-1.8	5.4
3	-2.1	-0.1	1.3	-2.0	-1.4	3.4
4	-4.0	0.7	3.3	-4.7	-2.6	7.3
5	-1.7	-0.4	0.0	-1.3	-0.4	1.7
6	-3.3	0.4	2.3	-3.7	-1.9	5.6
7	-3.4	0.5	2.4	-3.9	-1.9	5.8
RANGE 1	-	-	-	4.7	2.6	7.3
RANGE 2	-	-	-	1.6	0.4	2.0
RANGE 3	-	-	-	0.3	0.1	0.4

Notes:
1) All stresses are in KSI
2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.
3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.
4) Stress intensity range 3 is defined by load cases 2, 6, and 7.
5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-32

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-6

CASE	INSIDE			INSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-4.7	-6.0	-0.8	1.3	-5.2	3.9
2	-8.8	-8.1	6.1	-0.7	-14.2	14.9
3	-4.9	-6.2	-0.4	1.3	-5.8	4.5
4	-11.6	-10.1	9.2	-1.5	-19.3	20.8
5	-3.7	-5.9	-2.7	2.2	-3.2	1.0
6	-9.5	-8.5	7.0	-1.0	-15.5	16.5
7	-9.7	-8.9	6.8	-0.8	-15.7	16.5
RANGE 1	-	-	-	3.7	19.3	20.8
RANGE 2	-	-	-	2.0	9.0	11.0
RANGE 3	-	-	-	0.3	1.5	1.6

Notes:
1) All stresses are in KSI

2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.

3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.

4) Stress intensity range 3 is defined by load cases 2, 6, and 7.

5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-33

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-6

CASE	OUTSIDE			OUTSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-1.4	6.9	3.7	-8.3	3.2	5.1
2	-1.7	20.2	17.8	-21.9	2.4	19.5
3	-1.4	8.2	5.0	-9.6	3.2	6.4
4	-2.1	27.8	25.0	-29.9	2.8	27.1
5	-1.3	4.6	1.2	-5.9	3.4	2.5
6	-1.8	22.3	19.9	-24.1	2.4	21.7
7	-1.9	22.6	19.9	-24.5	2.7	21.8
RANGE 1	-	-	-	29.9	3.4	27.1
RANGE 2	-	-	-	13.6	0.8	14.4
RANGE 3	-	-	-	2.6	0.3	2.3

Notes:
1) All stresses are in KSI

2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.

3) Stress intensity range 2 is defined as the second larges stress range. It utilizes load cases 1,2, and 3.

4) Stress intensity range 3 is defined by load cases 2, 6, and 7.

5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-34

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-7

CASE	INSIDE RAD	INSIDE LONG	INSIDE HOOP	INSIDE R-L	INSIDE L-H	INSIDE H-R
1	-2.2	-0.8	6.8	-1.4	-7.6	9.0
2	-2.5	-4.0	-1.9	1.5	-2.1	0.6
3	-2.0	-1.2	3.9	-0.8	-5.1	5.9
4	-3.2	-5.8	-4.4	2.6	-1.4	-1.2
5	-1.5	-0.8	3.0	-0.7	-3.8	4.5
6	-2.6	-4.5	-3.2	1.9	-1.3	-0.6
7	-2.7	-4.5	-2.7	1.8	-1.8	0.0
RANGE 1	-	-	-	4.0	7.6	10.2
RANGE 2	-	-	-	2.9	5.5	8.4
RANGE 3	-	-	-	0.4	0.8	1.2

Notes:
1) All stresses are in KSI
2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.
3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.
4) Stress intensity range 3 is defined by load cases 2, 6, and 7.
5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-35

PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE

STRESS LINE-7

CASE	OUTSIDE			OUTSIDE		
	RAD	LONG	HOOP	R-L	L-H	H-R
1	-0.4	2.3	7.5	-2.7	-5.2	7.9
2	-0.7	-4.5	-0.1	3.8	-4.4	0.6
3	-0.4	0.2	4.6	-0.6	-4.4	5.0
4	-0.9	-6.7	-1.5	5.8	-5.2	-0.6
5	-0.3	0.1	3.4	-0.4	-3.3	3.7
6	-0.8	-5.6	-1.2	4.8	-4.4	-0.4
7	-0.8	-5.4	-0.7	4.6	-4.7	0.1
RANGE 1	-	-	-	8.5	5.2	8.5
RANGE 2	-	-	-	6.5	0.8	7.3
RANGE 3	-	-	-	1.0	0.3	1.0

Notes: 1) All stresses are in KSI

2) Stress intensity range 1 is defined as the largest stress range. It utilizes all seven load cases and the zero stress state.

3) Stress intensity range 2 is defined as the second largest stress range. It utilizes load cases 1, 2, and 3.

4) Stress intensity range 3 is defined by load cases 2, 6, and 7.

5) Tabulated stress is due to thermal and pressure loading only.

PROPRIETARY

Table 8-36

PRIMARY PLUS SECONDARY AXIAL LOADING

LOAD CASE	SLEEVE (LBS)	TUBE (LBS)
1	69	50
2	-496	760
3	-75	126
4	-723	1106
5	-57	-94
6	-584	867
7	-572	848
RANGE 1	792	1200
RANGE 2	565	710
RANGE 3	88	107

MAXIMUM SHEAR STRESS INTENSITY RANGE

LOAD RANGE	BRAZE (KSI)	WELD (KSI)
RANGE 1	3.9	3.9
RANGE 2	2.8	2.8
RANGE 3	0.4	0.4

Notes: 1) Stress ranges 1, 2 and 3 are described in Table 8-35.

2) Shear stress was calculated by using a required fabrication minimum weld or braze length of 0.25 inches as per the intent of the ASME Code, Section XI.

PROPRIETARY

Table 8-37

PEAK STRESS INTENSITY RANGE

RANGE - 1 -- INSIDE

LINE NO.	PRIMARY PLUS SECONDARY STRESS				TOTAL[5] PEAK STRESS
	PRES. + TH[1]	OBE[2]	S[3]	TOTAL[4]	
1	19.3	2.8	4.6	26.7	29.4
2	10.1	2.8	4.6	17.5	87.5
3	11.5	2.8	4.6	18.9	94.5
4	12.1	2.8	4.6	19.5	19.5
5	14.2	2.8	4.6	21.6	21.6
6	20.8	2.8	4.6	28.2	31.0
7	10.2	2.8	4.6	17.6	19.4

NOTES:

1) Stress taken from the tabulation of primary plus secondary stress due to pressure and thermal considerations.

2) Range of OBE stress.

3) Stress taken as maximum value from tubesheet/support plate interaction calculation.

4) Total stress is the summation of primary plus secondary stresses due to pressure, thermal, OBE and tubesheet support plate interaction.

5) Total peak stress is the product of the total primary plus secondary stress multiplied by the appropriate stress intensification factor for each line.

PROPRIETARY

Table 8-38

PEAK STRESS INTENSITY RANGE

RANGE - 1 -- OUTSIDE

LINE NO.	PRIMARY PLUS SECONDARY STRESS				TOTAL[5] PEAK STRESS
	PRES. + TH[1]	OBE[2]	S[3]	TOTAL[4]	
1	22.3	2.8	4.6	29.7	32.7
2	22.6	2.8	4.6	30.0	30.0
3	22.8	2.8	4.6	30.2	30.2
4	7.3	2.8	4.6	14.7	73.5
5	7.3	2.8	4.6	14.7	73.5
6	29.9	2.8	4.6	37.3	41.0
7	8.5	2.8	4.6	15.9	17.5

NOTES:

1) Stress taken from the tabulation of primary plus secondary stress due to pressure and thermal considerations.

2) Range of OBE stress.

3) Stress taken as maximum value from tubesheet/support plate interaction calculation.

4) Total stress is the summation of primary plus secondary stresses due to pressure, thermal, OBE and tubesheet support plate interaction.

5) Total peak stress is the product of the total primary plus secondary stress multiplied by the appropriate stress intensification factor for each line.

PROPRIETARY

Table 8-39

PEAK STRESS INTENSITY RANGE

RANGE - 2 -- INSIDE

LINE NO.	PRIMARY PLUS SECONDARY STRESS				TOTAL[5] PEAK STRESS
	PRES. + TH[1]	OBE[2]	S[3]	TOTAL[4]	
1	10.7	-	1.3	12.0	13.2
2	6.2	-	1.3	7.5	37.5
3	4.6	-	1.3	5.9	29.5
4	9.4	-	1.3	10.7	10.7
5	11.0	-	1.3	12.3	12.3
6	11.0	-	1.3	12.3	13.5
7	8.4	-	1.3	9.7	10.7

NOTES: 1) Stress taken from tabulation of primary plus secondary stress due to pressure and thermal considerations.

2) Range of OBE stress.

3) Stress taken as maximum value from tubesheet/support plate interaction calculation.

4) Total stress is the summation of primary plus secondary stresses due to pressure, thermal, OBE and tubesheet support plate interaction.

5) Total peak stress is the product of the total primary plus secondary stress multiplied by the appropriate stress intensification factor for each line.

Table 8-40

PEAK STRESS INTENSITY RANGE

RANGE - 2 -- OUTSIDE

LINE NO.	PRIMARY PLUS SECONDARY STRESS				TOTAL[5] PEAK STRESS
	PRES. + TH[1]	OBE[2]	S[3]	TOTAL[4]	
1	12.3	-	1.3	13.6	15.0
2	12.1	-	1.3	13.4	13.4
3	12.3	-	1.3	13.6	13.6
4	5.2	-	1.3	6.5	32.5
5	2.0	-	1.3	3.3	16.5
6	14.4	-	1.3	15.7	17.3
7	7.3	-	1.3	8.6	9.5

NOTES:
1) Stress are taken from tabulation of primary plus secondary stress due to pressure and thermal considerations.
2) Range of OBE stress.
3) Stress taken as maximum value from tubesheet/support plate interaction calculation.
4) Total stress is the summation of primary plus secondary stresses due to pressure, thermal, OBE and tubesheet support plate interaction.
5) Total peak stress is the product of the total primary plus secondary stress multiplied by the appropriate stress intensification factor for each line.

PROPRIETARY

Table 8-41

PEAK STRESS INTENSITY RANGE

RANGE - 3 -- INSIDE

LINE NO.	PRIMARY PLUS SECONDARY STRESS				TOTAL[5] PEAK STRESS
	PRES. + TH[1]	OBE[2]	S[3]	TOTAL[4]	
1	1.7	-	0.3	2.0	2.2
2	0.9	-	0.3	1.2	6.0
3	0.8	-	0.3	1.1	5.5
4	1.3	-	0.3	1.6	1.6
5	1.6	-	0.3	1.9	1.9
6	1.6	-	0.3	1.9	2.1
7	1.2	-	0.3	1.5	1.7

NOTES:

1) Stress are taken from tabulation of primary plus secondary stress due to pressure and thermal considerations.

2) Range of OBE stress.

3) Stress taken as maximum value from tubesheet/support plate interaction calculation.

4) Total stress is the summation of primary plus secondary stresses due to pressure, thermal, OBE and tubesheet support plate interaction.

5) Total peak stress is the product of the total primary plus secondary stress multiplied by the appropriate stress intensification factor for each line.

PROPRIETARY

Table 8-42

PEAK STRESS INTENSITY RANGE

RANGE - 3 -- OUTSIDE

LINE NO.	PRIMARY PLUS SECONDARY STRESS				TOTAL[5] PEAK STRESS
	PRES. + TH[1]	OBE[2]	S[3]	TOTAL[4]	
1	1.9	-	0.3	2.2	2.4
2	1.8	-	0.3	2.1	2.1
3	1.8	-	0.3	2.1	2.1
4	0.8	-	0.3	1.1	5.5
5	0.4	-	0.3	0.7	3.5
6	2.6	-	0.3	2.9	3.2
7	1.0	-	0.3	1.3	1.4

NOTES:

1) Stress are taken from tabulation of primary plus secondary stress due to pressure and thermal considerations.
2) Range of OBE stress.
3) Stress taken as maximum value from tubesheet/support plate interaction calculation.
4) Total stress is the summation of primary plus secondary stresses due to pressure, thermal, OBE and tubesheet support plate interaction.
5) Total peak stress is the product of the total primary plus secondary stress multiplied by the appropriate stress intensification factor for each line.

PROPRIETARY

Table 8-43

36" SLEEVE FREQUENCY COMPARISON (HZ)

Model No.	Model Description	Tube Boundary Conditions 1	Tube Boundary Conditions 2
1	Original Tube	30.26	25.29
2	Sleeved Original Tube	30.33	25.42
3	Sleeved Original Tube (tube severed below top of tube-sheet)	29.08	21.15
	Variation (%) Case (1-3)/Case 3	3.90	16.37

The boundary conditions are:

1) Tube supported at all support plates and at the top of the tubesheet.

2) As in (1) but with no support at the top of the tubesheet.

PROPRIETARY

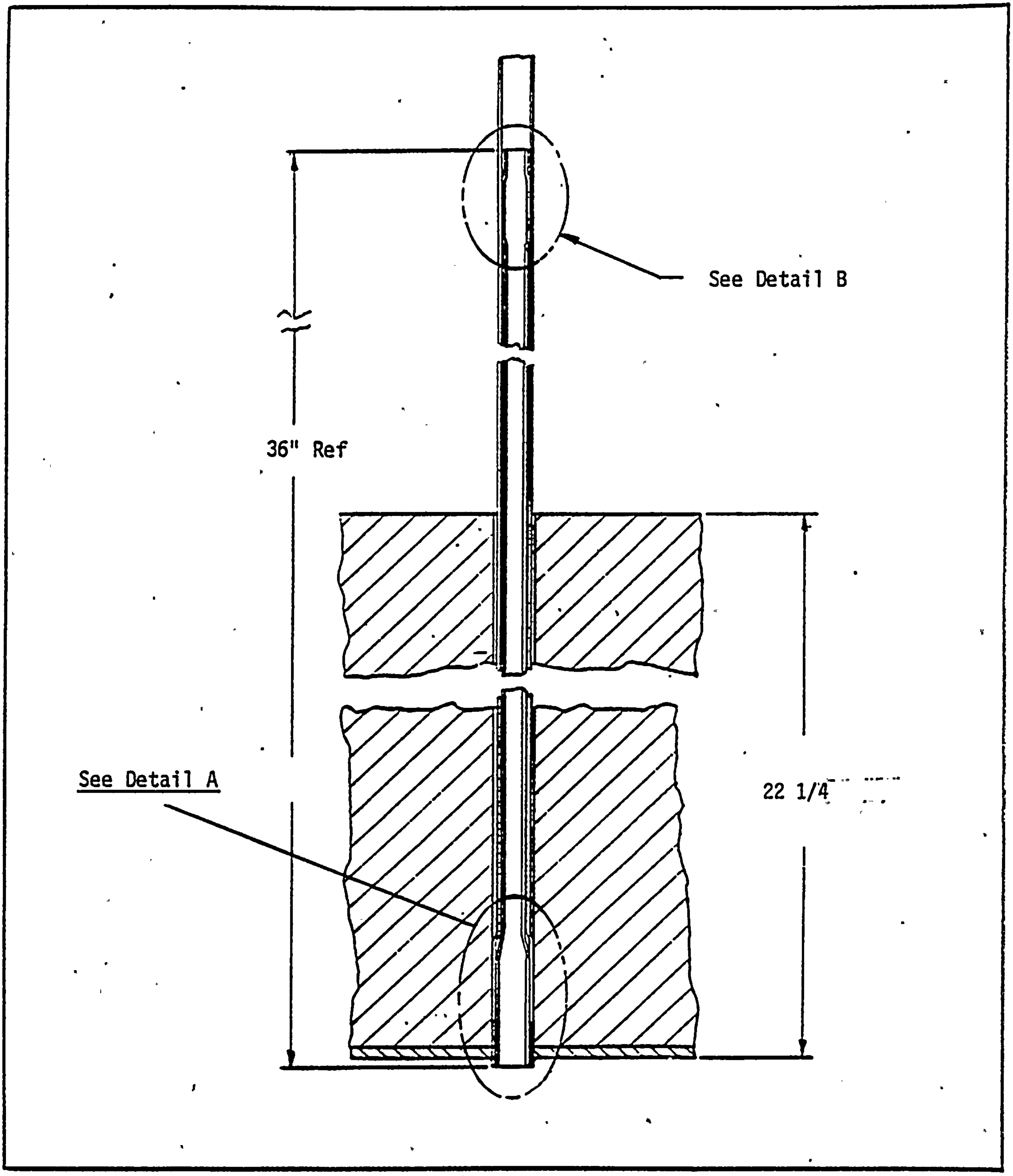
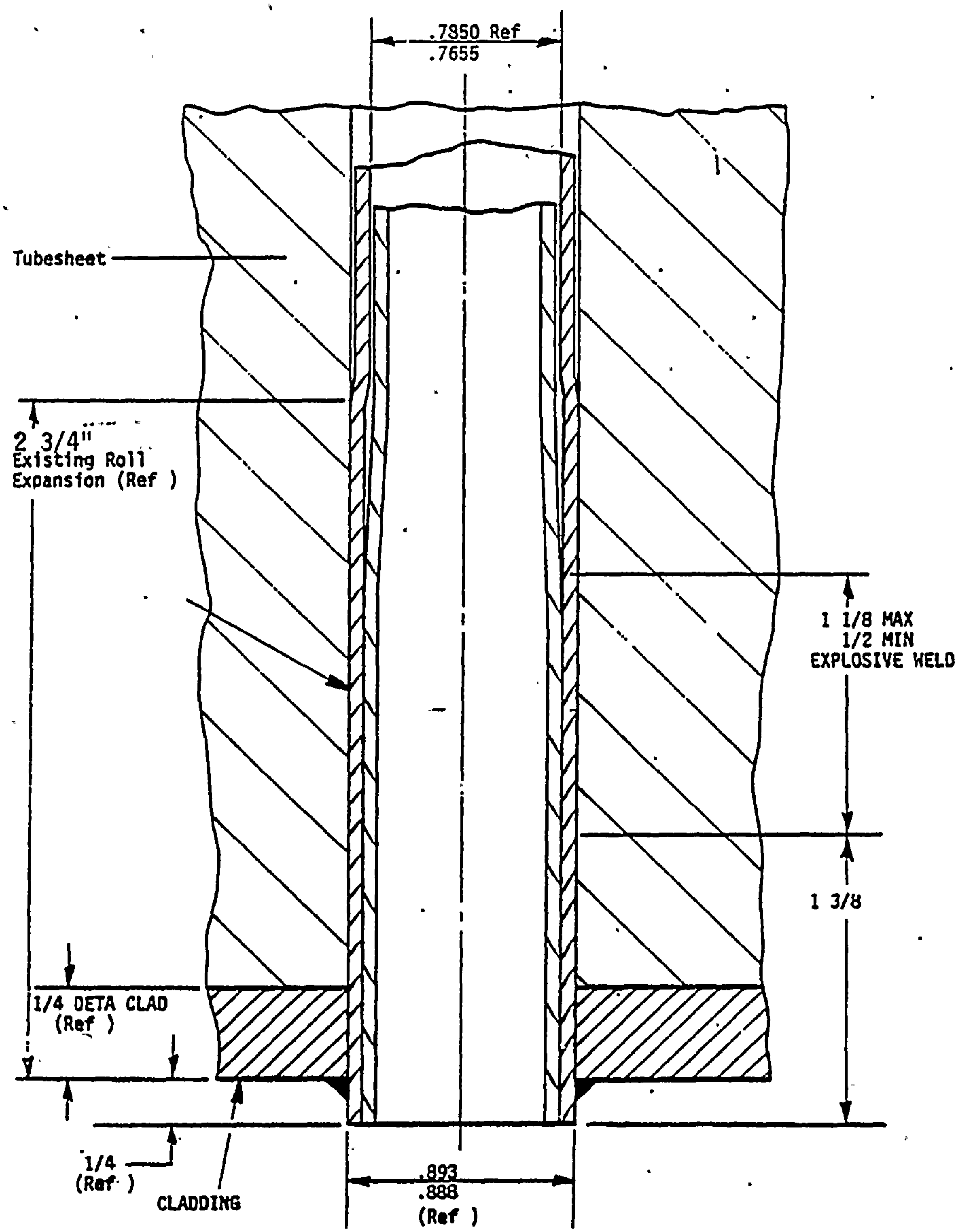


Figure 1 Tube/Sleeve Assembly

PROPRIETARY

FIGURE 8 - 1

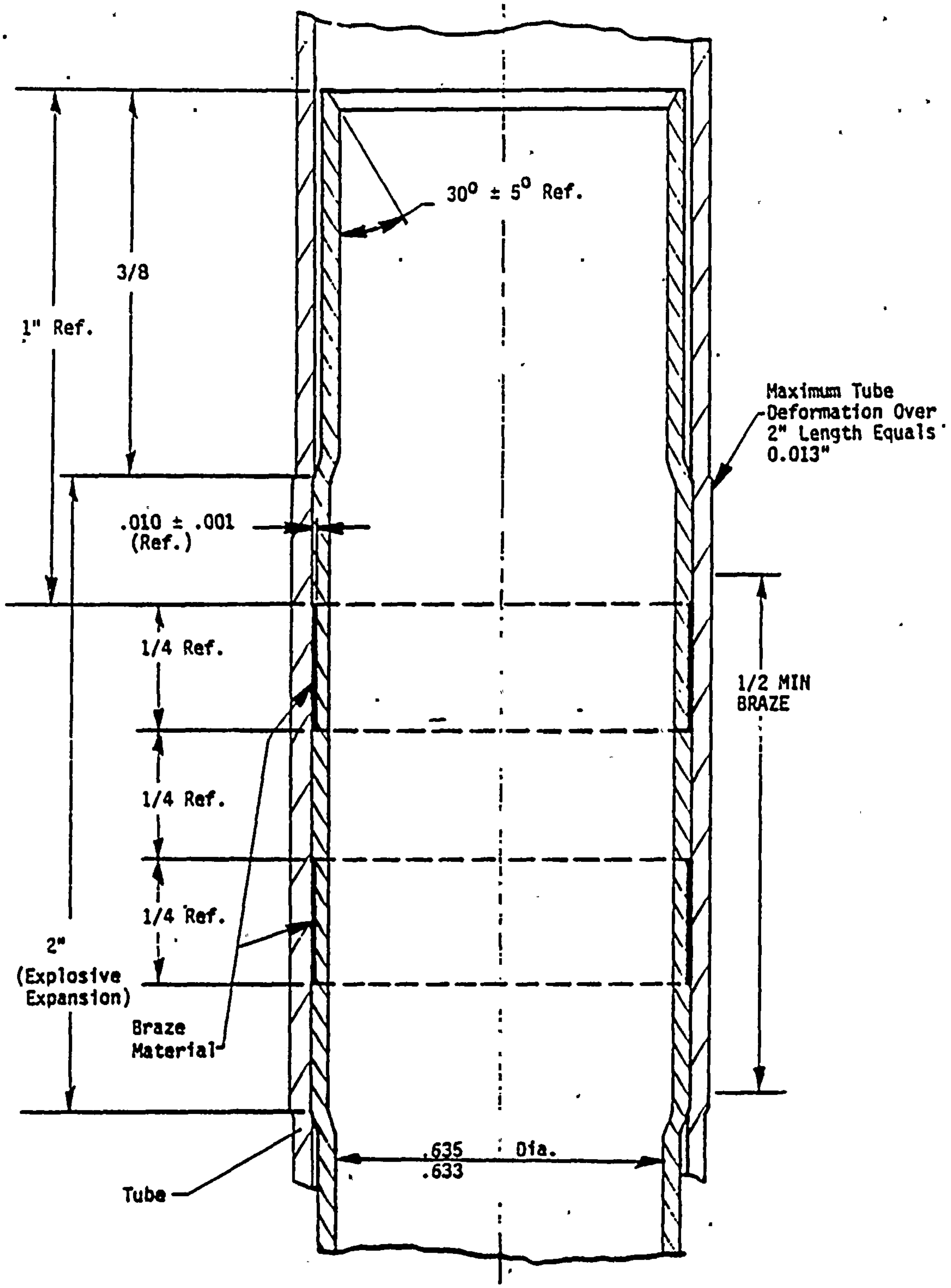


Detail A

Figure 2 Lower Explosive Weld Detail

PROPRIETARY

FIGURE 8 - 2



Detail B

Figure 3 Upper Explosive Expansion/Braze Joint

PROPRIETARY

FIGURE 8 - 3

PROPRIETARY

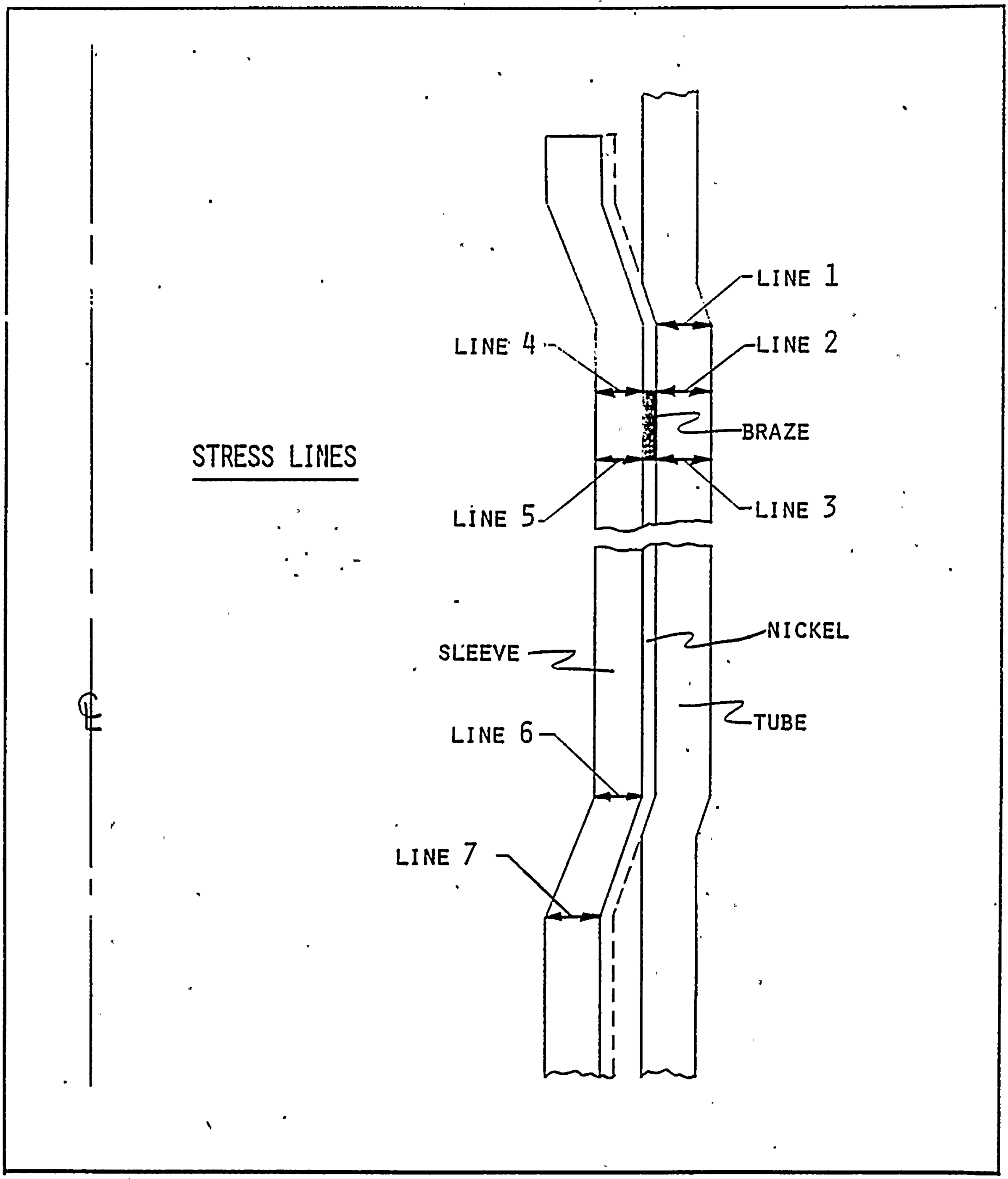
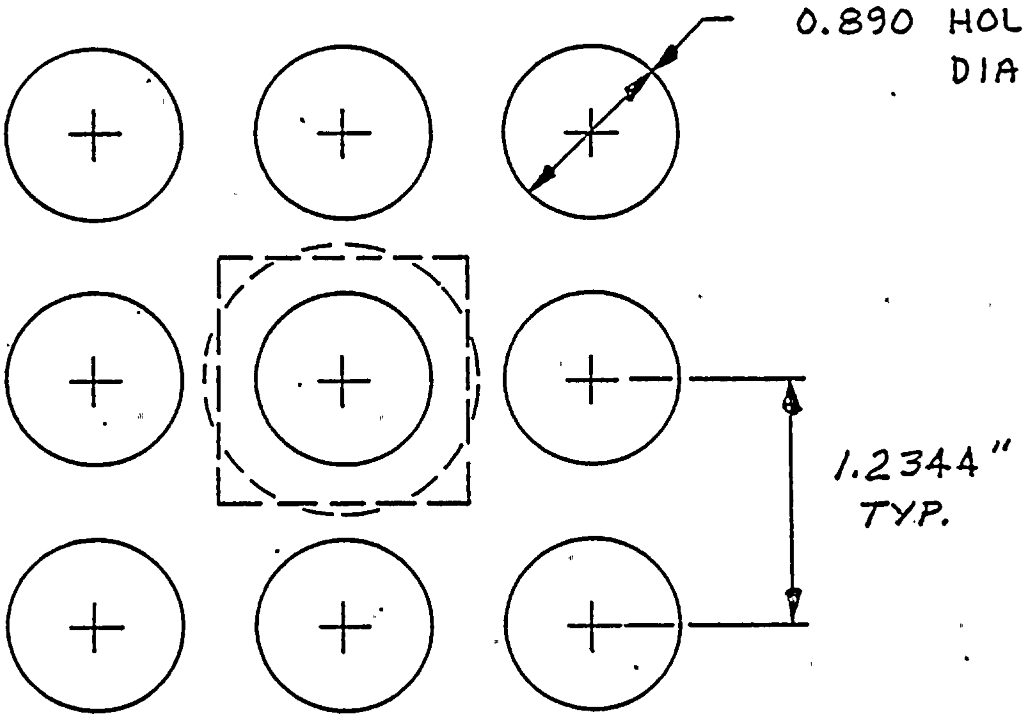


FIGURE 8-4

PROPRIETARY



UNIT CELL AREA = $1.2344^2 = 1.524\ IN^2$

EQUIVALENT AREA = πR^2

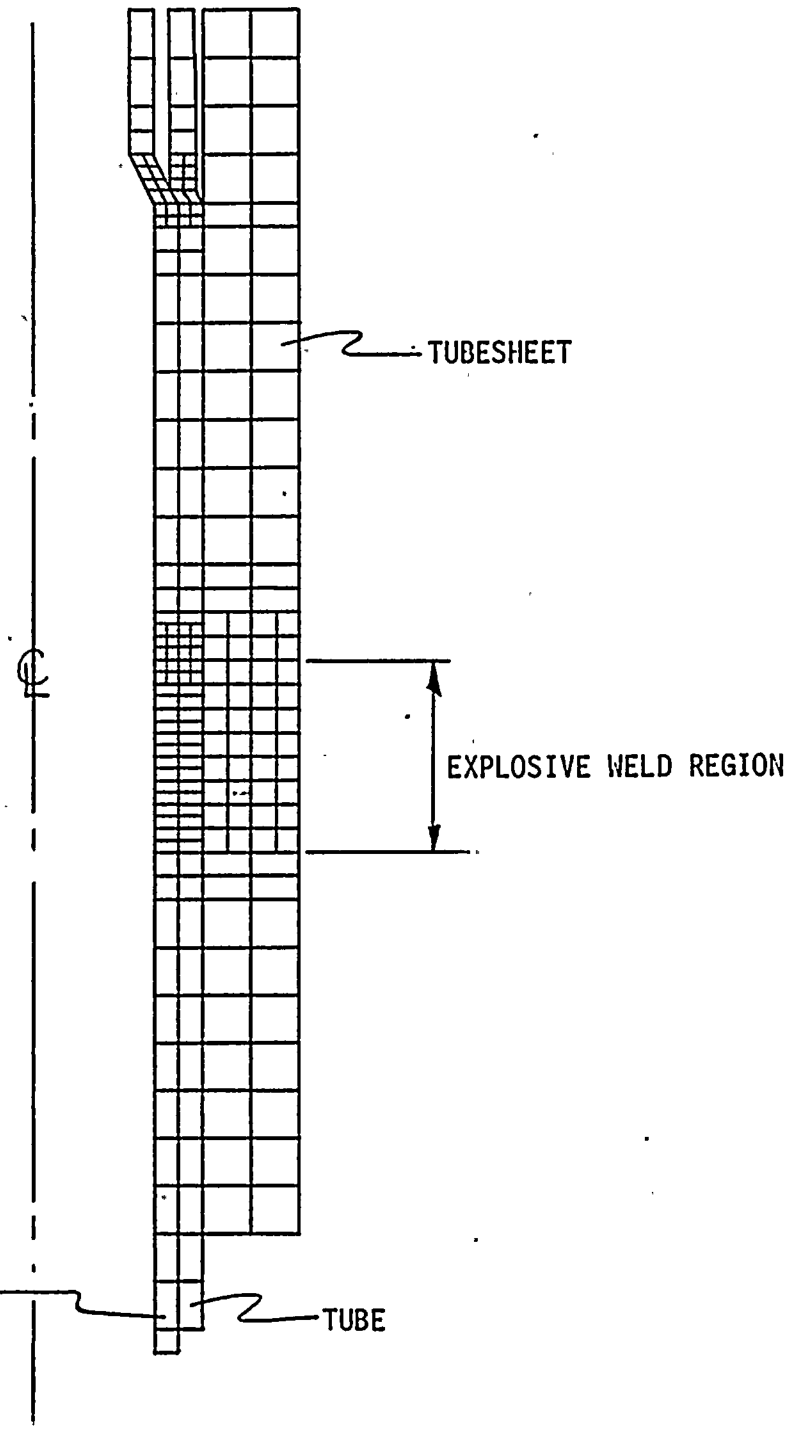
$\pi R^2 = 1.254$

$R = 0.6964''$

EQUIVALENT TUBESHEET AREA

Figure 8-5

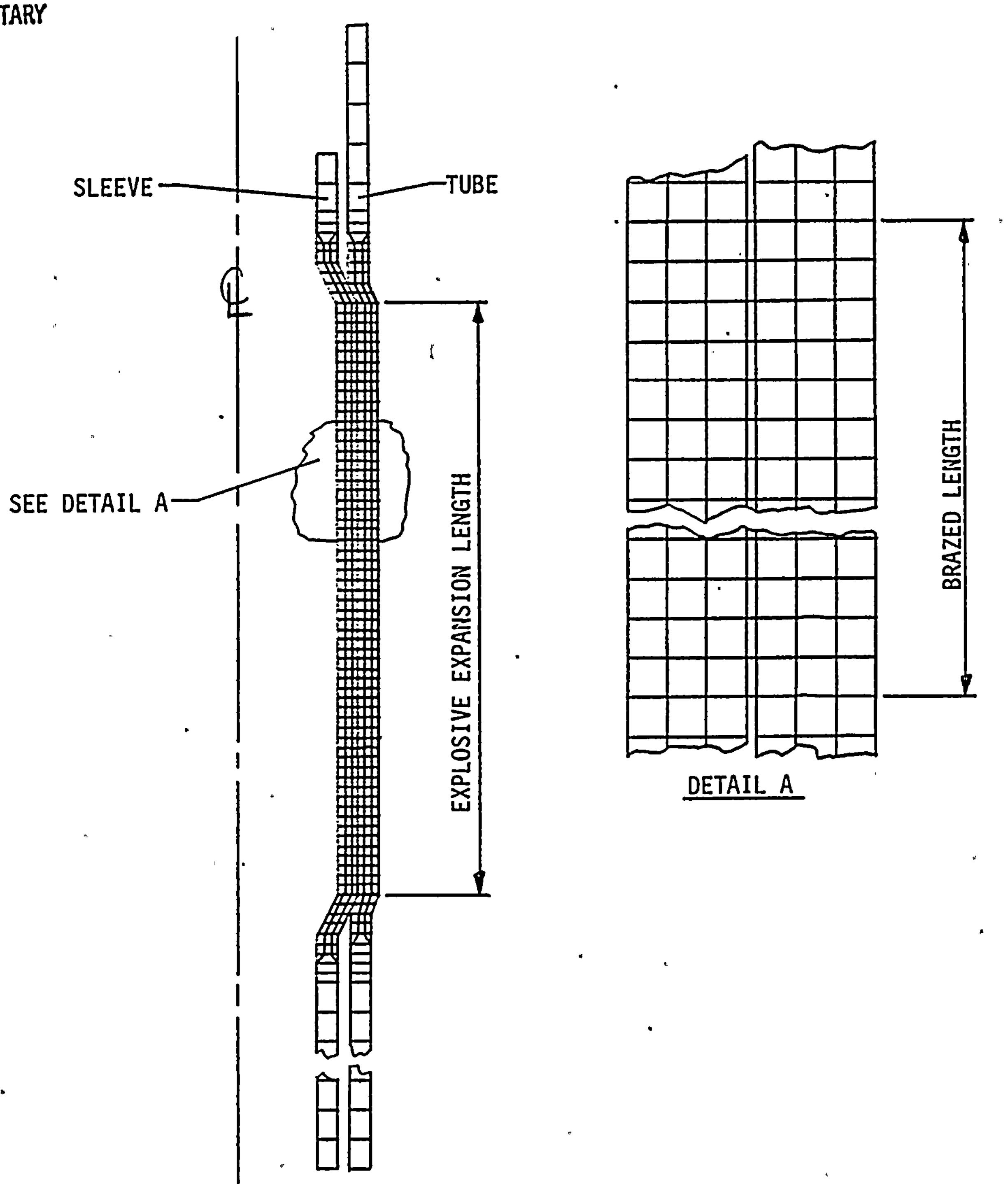
PROPRIETARY



SLEEVE LOWER END EXPLOSIVE WELD ATTACHMENT

Figure 8-6

PROPRIETARY



SLEEVE UPPER END BRAZED/EXPANDED JOINT

Figure 8-7

PROPRIETARY

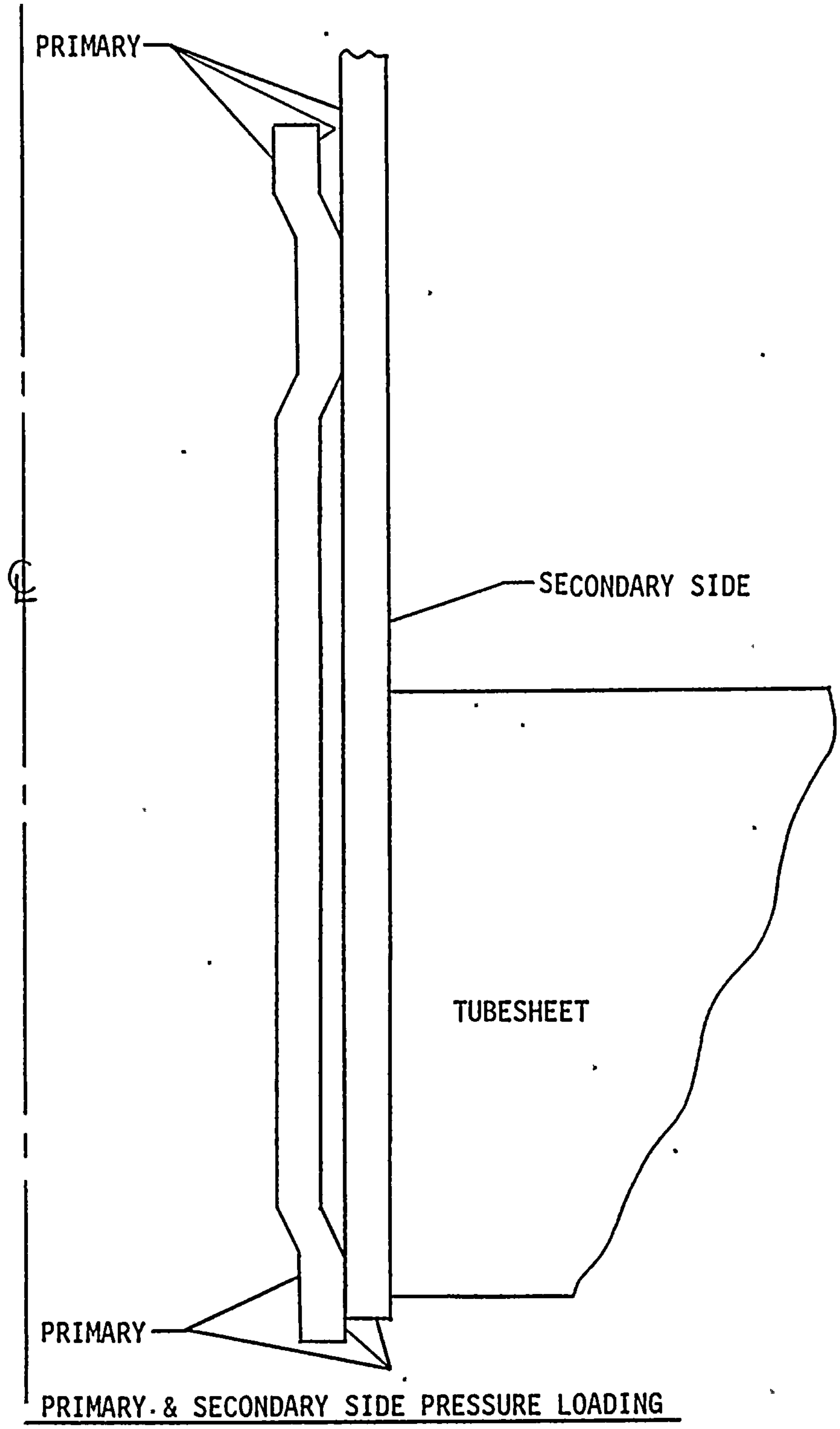
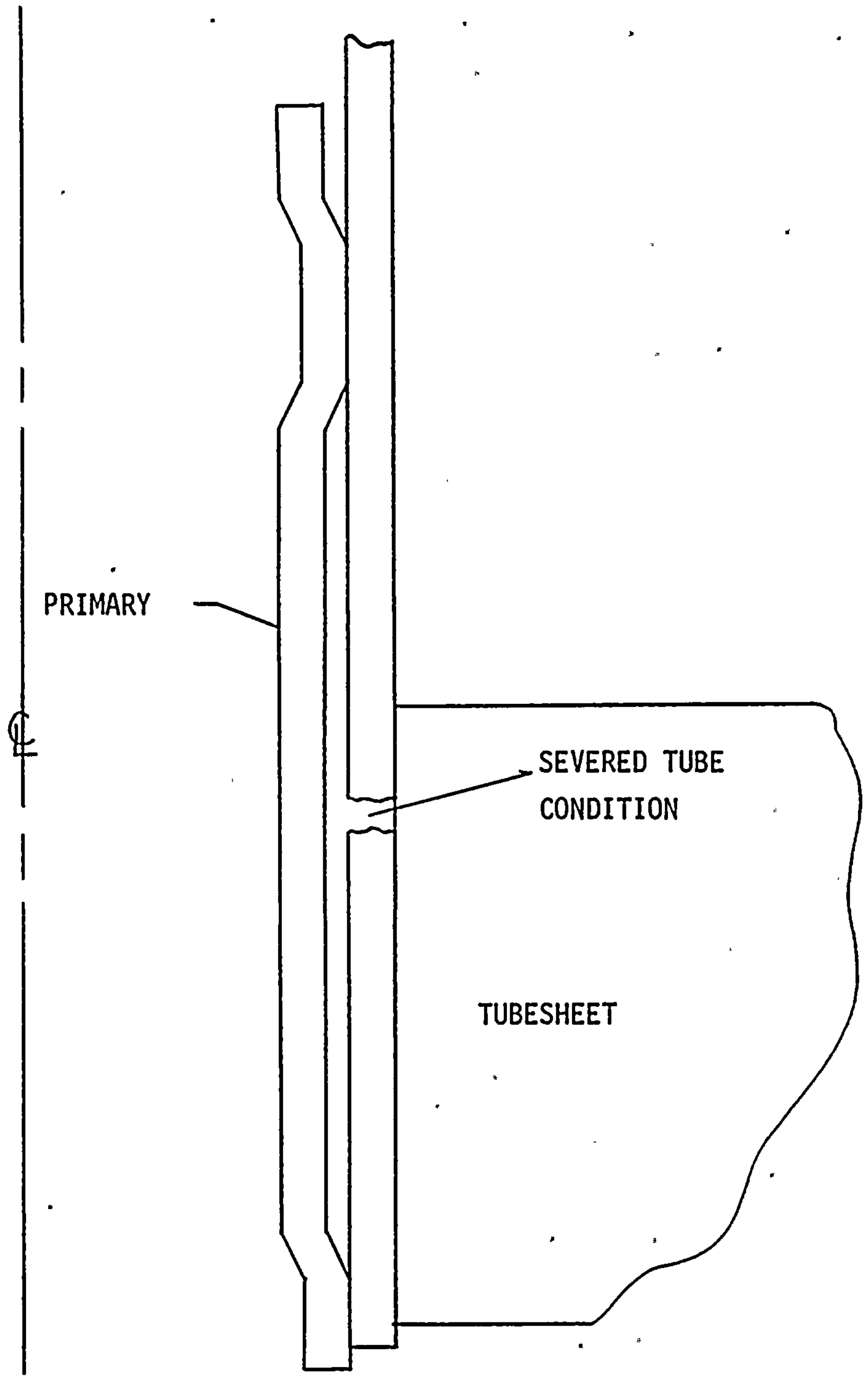


Figure 8-8

PROPRIETARY



PRIMARY SIDE DESIGN PRESSURE LOADING

Figure 8-9

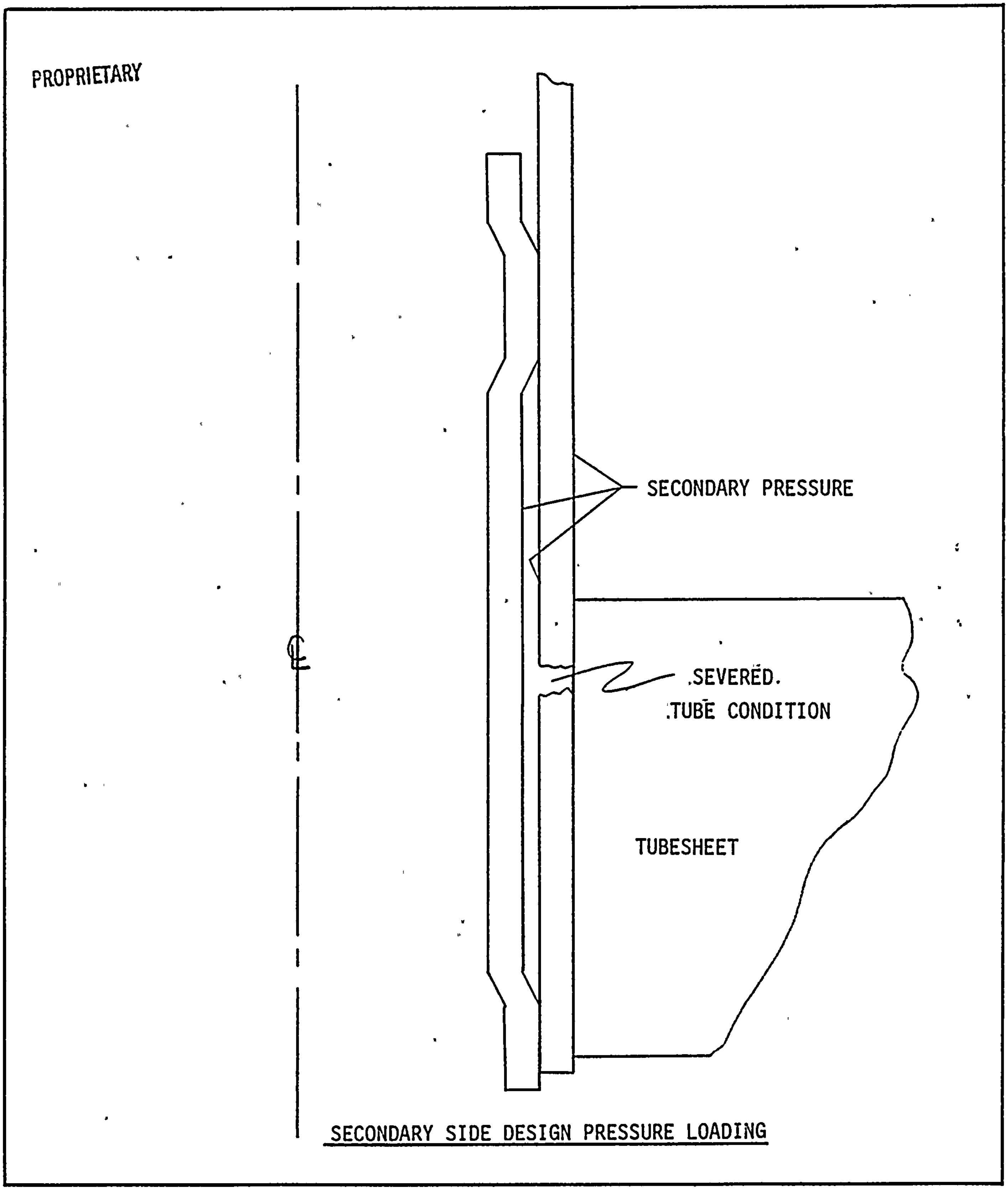

PROPRIETARY
SECONDARY PRESSURE
SEVERED.
TUBE CONDITION
TUBESHEET
SECONDARY SIDE DESIGN PRESSURE LOADING

Figure 8-10

9.0 INSTALLATION

9.1 Background

With the successful installation of 21 bimettallic sealable sleeves at Rochester Gas & Electric's Ginna station, the techncal adequacy of the basic sleeve design and installation process have been verified. Additional confirmation has been obtained by comparing subsequent Non-Destuctive Examinations to the original baseline inspection results. The comparisons indicate that no deterioration has occured on the 21 test sleeves.

The present process has been developed and qualified in order for the mass installation of sleeves to be effected by remotely controlled tooling. The increased installation rates achieved allows the use of sleeving as a preventative maintenance technique which can be conducted off critical path during a refueling outage while also minimizing radiation exposure by utilizing automated equipment.

The process used to attach the sealable sleeve (Figure 9-1) to sound tube material was specifically selected to avoid excess working of the sleeve material. The sleeve is explosively expanded at the upper end and sealed with an induction brazing technique utilizing a gold-alloy material. Corrosion testing of material having undergone explosive expansion demonstrates significantly higher resistance to stress corrosion cracking than material undergoing mechanical expansion (rolling), which cold works the inside surface of the sleeve. The lower end of the tube is then explosively welded to the tube by an explosive charge.

9.2 Sleeve Installation Process

The sleeve installation process includes the following basic installation steps.

- o Clean the Steam Generator Tube
- o Insert the sleeve and expand
- o Braze sleeve to tube at upper attachment
- o Explosively weld the sleeve to the tube at the lower attachment.

Since these steps each involve a tooling change, a batch process was qualified to minimize tooling changes. Batching also has the advantage of being able to train craft labor to perform one or two functions as opposed to each laborer having to learn all the installation steps. Batch sizes are flexible to match the requirements of the job.

9.2.1 Clean the Steam Generator Tube

Installation of the sleeve requires the removal of loose oxides from the tube in the vicinity of the explosive weld and cleaning the tube to base metal in the vicinity of the braze. Cleaning is accomplished using a combination hone and swab (Figure 9-2). The hone/swab assembly is in the proper location, the cleaning equipment will automatically rotate the hone/swab while oscillating the assembly over the 5 inch long area of the tube to be cleaned. In the braze region the cleaning operation takes two minutes. Thirty seconds is sufficient at the explosive weld.

The hone performs the actual oxide removal process. The swab traps and removes grit/oxide from the surface of the steam generator tubing. A single hone and swab assembly is used to clean a tube. After the tube is clean, the assembly is withdrawn from the tube and from the steam generator by the automated tooling. A new hone/swab assembly is changed out by the tooling opertor outside the steam generator head. While the hone/swab is being changed, the manipulator can index to the next tube which is to be cleaned and the process repeated.

9.2.2 Insert the Sleeve and Expand

After cleaning a batch of steam generator tubes, sleeves are inserted into the tubes and expanded in the braze region. To expand the sleeve an explosive expansion cartridge (Figure 9-3) is used. The cartridge is inserted into the sleeve outside the steam generator. The sleeve/cartridge assembly is then loaded onto the elevator. The tooling indexes to the correct tube and inserts the assembly into the tube.

Once the sleeve is inserted into the tube and verified using the TV camera located on the manipulator, the tooling operator connects the electrical leads which extend from the expansion cartridge. A qualified explosives man located in the central control area tests the continuity of the electrical leads and detonates the cartridge. The cartridge expands the sleeve into the steam generator tube over the two inch bladder length.

Following detonation the cartridge is removed from the sleeve by the automatic manipulator. The sleeve remains in position as the result of the mechanical joint caused by the explosive expansion. The cartridge is removed from the manipulator by the tooling operator and a new sleeve and explosive cartridge assembly is installed on the manipulator and the process

repeated. The spent explosive cartridge can be cleaned, reloaded and used again. This work takes place outside containment and off critical path.

9.2.3 Braze the Sleeve to the Tube at Upper Attachment

After sleeve insertion and expansion, a batch of sleeves are brazed to the tubes at the upper joint. Brazing is initiated by the installation of the braze wand on the sleeve manipulator elevator. The braze wand is a water cooled induction heater which uses a fiber optic system to measure and control the temperature cycle.

Before insertion of the wand into the sleeve to be brazed, argon flow must first be established for 5 minutes. The purge manipulator inserts a temporary plug in the opposite tube end from the end being sleeved. The plug is designed to permit a flow of argon gas to be introduced into the tube. Flow of gas for the first 5 minutes is controlled to 50 cubic feet per hour (CFH). After this flow rate and time requirement have been met, the gas flow is reduced to 20 CFH and the braze wand is inserted.

When inserted into the sleeve the braze wand is accurately positioned relative to the sleeve expanded area and braze rings. The heating cycle begins when proper braze wand insertion is confirmed. Heating to the braze temperature is accomplished rapidly, usually in about 1 1/2 minutes. Once the braze temperature of 1830°F $\pm$ 20°F is reached, the automatic controller holds the temperature for a minimum of two minutes. After the two minute braze hold, the temperature is reduced to 1525°F $\pm$ 30°F and the temperature is held again for 5 minutes to thermally treat the inconel 600 sleeve and tube. Following the thermal treatment, power is shut off to the braze wand and the temperature reduced.

During the 5 minute thermal treatment of the first sleeve being brazed, the purge flow is initiated on the second sleeve. Therefore when the thermal cycle is complete and the braze wand has cooled, the wand is removed from the first sleeve and inserted in the second sleeve. Since the five minute purge requirement has been met, brazing can start again as soon as the argon flow is reduced to 20 CFH.

Throughout the entire braze operation, the temperature is automatically controlled. An optical fiber is built into the braze wand. This fiber gathers light emitted by the hot sleeve wall and transmits it to an analyzer. In the analyzer the light is split into two color components, and the intensity of each component is detected. The ration of the two detector signals is a linear function of temperature.

The temperature data is fed to an automatic controller. Using this automatic feedback system, the power to the induction heater can be very accurately controlled. Good power control and automatic temperature feedback assures the ability to accurately control the temperatures well within the stated limits.

9.2.4 Explosive Weld the Sleeve to the Tube at the Lower Attachment

Explosively welding the sleeve to the tube near the primary face of the tubesheet is the final step in the sleeve installation process. An explosive weld cartridge (Figure 9-4) is inserted onto the elevator. The sleeve manipulator is positioned over the proper sleeve and the elevator inserts the weld cartridge. The design of the weld cartridge is such that it automatically releases from the tooling by spring action when properly inserted in the sleeve.

Insertion is further confirmed by video. The manipulator is moved to the side and the operator attaches the two electrical lead wires which are outside the steam generator to a junction box. When the wires are installed, the operator turns control over to the explosives expert located in the command center. The explosives expert checks electrical continuity and then detonates the device.

The detonation shatters the weld cartridge and welds the sleeve to the tubing. Following the detonation of a batch of the weld cartridges, the debris is removed from the steam generator head. All materials used in this process and all the sleeving operations have been checked for contaminants and are qualified for nuclear use.

9.3 Tooling Description

The remote tooling, some of which is pictured at the end of this section, includes an automated manipulator which, when installed in the steam generator channel head, provides a mechanism for remote cleaning of the tube to be sleeved, insertion of the sleeve and explosive expansion device, placement of and removal of the induction braze wand and placement of an explosive weld cartridge which seals the lower end of the sleeve.

In addition, during the brazing operation, a gas purge is initiated through the tube and around the sleeve by means of an ARGON purge system remotely operated via a manipulator located in the channel head opposite the sleeving manipulator. Throughout the sleeving process, all functions and operations which take place in the channel heads are monitored from an operating station which is located outside of the containment building. Some of the specific details of this sleeving system are as follows:

9.3.1 Sleeving Manipulator

Figure 9-5 illustrates the sleeving manipulator design. A temporary rail is installed in the head of the steam generator by the use of expanding mandrels which are inserted into selected peripheral steam generator tubes. The beam and carriage is then installed. It is supported in the outer periphery by the rail and at the center of the tube bundle by a pivoted bearing asembly affixed to selected tubes by expanding mandrels. Supported in this manner, the manipulator is strong and exhibits little deflection under the loads involved in the sleeving process. The carriage is positioned by a combination of radial travel along the beam and circumferential travel (theta motion) of the beam around the peripheral track. The carriage is designed to receive specified attachments which perform the various sleeving operations. It is equiped with a cable-driven elevator which allows installation of attachments through the manway without steam generator entry.

The manipulator is controlled by a programmable solid-state computer with keyboard input and liquid crystal alpha-numerical display. The desired manipulator location is entered into the computer by entry of the designated tube row and column numbers. It is instructed to return to the manway by indexing the key entitled "manway".

Manipulator positioning is initiated by the press of a button. Actual manipulator position is relayed to the computer by means of a servo-feedback system. Provisions are made for manual manipulator positioning with the ability to correct the computer program at any point during operation.

9.3.2 Manipulator Attachments

Specialized attachments for the automated manipulator are provided for the various sleeving operations (See Figures 9-6 thru 9-8). These operations include:

1. honing of the tube to bright metal
2. cleaning of the tube following honing
3. insertion and expansion of the sleeve into the tube
4. insertion, operation and removal of the brazing equipment
5. placement and detonation of explosive weld charges.

All attachment controls are located at the centralized control area.

9.3.3 Purge System

The purge system includes a remotely operated manipulator (based on the Zetec SM-4) which is installed in the coolant head opposite the sleeving manipulator (See Figure 9-9). The purge system manipulator positions a retractable hollow expanding plug through which the argon purge gas is passed. The system also includes all necessary remote equipment for the control and monitoring of the inerting purge gas during the brazing process. Location of the tube is by means of a labled template positioned on the channel head tubesheet. Manipulator/plug position is identified by use of a remote video camera.

9.3.4 Remote Brazing Equipment

The brazing equipment consists of an induction brazing power supply, (located in the proximity of the steam generator), braze heating wands, an optical braze temperature monitoring system, and recording devices for brazing parameters. All controls and parameter monitoring devices are located at the centralized control area.

9.3.5 Centralized Control Area

Separate consoles are provided for the control and monitoring of all aspects of the sleeving process. The consoles are permanently mounted in a mobile trailer for ease of transport (See Figures 9-10 and 9-11). The control trailer can be located at any point within 600 linear feet of the steam generator. The consoles are divided to perform seven distinct functions:

1. induction brazing indication and control and explosive expansion/weld control,
2. brazing purge and purge system manipulator control,
3. purge flow indication and control
4. sleeving manipulator attachment control,
5. sleeving automated manipulator control,
6. video recording and switching control, and
7. a data gathering computer control (local functions only).

These consoles are connected to a centralized cabling connection point external to the trailer for ease of deployment.

9.3.6 Manual Equipment and Operations

While the sleeving operations have been automated to the maximum practical extent, there remain some operations which do not lend themselves to automation.

These include:

9.3.6.1 Data Gathering Computer

This is a manually input computer which is provided for maintaining a historical record of tube sleeving operations (See Figure 9-12). The computer provides a visual CRT display of individual tube sleeving status as well as a hard copy printout of all work accomplished on each tube with dates and times. This system is especially helpful for maintaining a sleeving status when large numbers of tubes are being sleeved.

9.3.6.2 Installation of Manipulators

The sleeving and purge system manipulators must be manually installed by personnel entry into the steam generator channel heads. It has been demonstrated through mock-up testing that installation of both manipulators will not exceed 15 minutes and removal 9 minutes.

9.3.6.3 Installation of Manipulator Attachments

The specialized attachments to the automated sleeving manipulator must be manually inserted into the manipulator carriage elevator. This operation takes approximately 30 seconds per attachment being inserted by a person standing at the steam generator manway opening and does not require steam generator entry.

9 3.7 Audio and Video Systems

All personnel involved in the sleeve installation operations are in constant touch with each other via an extensive communications system. The voice transmittals can be monitored and/or taped for the purpose of informing oncoming shift personnel of the status of the sleeving operations and for record purposes.

A closed circuit video system is used to monitor all operations being performed in the steam generator channel heads as well as in the vicinity of the manway openings. The system also includes video tape recorders should visual records of the sleeving operations be necessary or desired.

The combination of these two systems contributes significantly to the efficiency of the overall operation. In addition, the ability of health physics personnel to remotely monitor the actions of and to communicate with personnel directly involved in sleeving operations results in minimizing radiation exposure significantly.

9.4 Radiation Exposure Control and Estimates

In order to make sleeving a viable preventative maintenance technique, radiation exposure control has been a primary consideration in the remote sleeving system development. As a result, the remote tooling limits the required entries into the steam genertor channel heads to the installation and removal of the manipulators. In addition, the changing of attachments required to perform various phases of the sleeve installation process will require only brief periods of personnel standing in front of the open steam generator manway.

One ALARA technique being employed is to reduce the frequency of these exposure periods by performing the sleeving process in batches. For example the cleaning snorkel and fitting is affixed to the sleeving manipulator elevator at the manway opening. It is then remotely indexed to each tube in the batch for cleaning. No additional approaches to the manway are required until all tubes in the batch are cleaned and the snorkel and fitting must be removed. Brazing of the upper end of the sleeve also employs the same principle. In addition, the exposure durations will be minimized through extensive training and certification of support personnel handling the attachments. The training will be conducted using steam generator mock-ups and duplicate tooling. Anti-C clothing will be worn and containment areas incorporated to simulate to the maximum extent possible actual work area configuration and conditions. This will result in minimal radiation exposure while realizing optimum efficiency in sleeve installation.

Time studies conducted during sleeve installation demonstrations indicate a radiation exposure of 0.177 rem per sleeve installed may be expected for the installation of 100 sleeves. Lower exposure levels can be expected on larger sleeving jobs where the fixed exposure associated with installing and removing the tooling can be spread over more sleeves.

Table 9-1 has detailed time and exposure estimates for the installation of 100 sleeves. The table is divided into fixed exposure associated with tooling installation and removal and variable exposure associated with the quantity of sleeves to be installed.

The following assumptions and time study results were used in ascertaining radiation exposure estimates:

Radiation dose rates

o In the channel heads	12 R/hr
o At the manway openings	2 R/hr
o General vicinity of the steam generator manway tent	0.1 R/hr
o General area of the reactor building away from the tent	0.01 R/hr

Time has been factored into these estimates for involvement of health physics and quality assurance personnel. It is assumed that intimate participation by them will be required 50% of the time expended by personnel actually involved in sleeving operations.

Table 9-1

Estimated Radiation Exposure

EXPOSURE CATEGORY	IN THE CHANNEL HEAD TIME (HRS)	IN THE CHANNEL HEAD EXPOSURE (MAN-REM) based on an assumed dose rate of 12R/hr.	AT THE MANWAY TIME (HRS)	AT THE MANWAY EXPOSURE (MAN-REM) based on an assumed dose rate of 2R/hr.	IN VICINITY OF THE STEAM GENERATOR HEAD TIME (HRS)	IN VICINITY OF THE STEAM GENERATOR HEAD EXPOSURE (MAN-REM) based on an assumed dose rate of 0.1R/hr.	GENERAL REACTOR BUILDING TIME (HRS)	GENERAL REACTOR BUILDING EXPOSURE (MAN-REM) based on an assumed dose rate of 0.01 R/hr.	TOTAL EXPOSURE
1) FIXED EXPOSURES									
A. TOOLING INSTALLATION									
(1) SLEEVING MANIPULATOR	0.166	2.0	0.416	0.832	0.5	0.05	1.66	0.016	
(2) PURGE MANIPULATOR	0.083	1.0	0.0166	0.033	0.133	0.013	0.833	0.008	
(3) AUDIO & VISUAL SYSTEMS	0.0	0.0	0.0	0.0	0.166	0.016	1.66	0.016	
B. TOOLING REMOVAL									
(1) SLEEVING MANIPULATOR	0.083	1.0	0.033	0.066	0.166	0.016	1.0	0.01	
(2) PURGE MANIPULATOR	0.05	0.6	0.0166	0.033	0.133	0.013	0.666	0.006	
(3) AUDIO & VISUAL SYSTEMS & GENERAL CLEAN UP	0.0	0.0	0.0	0.0	0.166	0.016	50	0.50	
C. TOTAL FIXED EXPOSURE	0.382	4.6	0.482	0.964	1.264	0.126	55.819	0.558	6.248
2) VARIABLE EXPOSURES (PER 100 SLEEVES)									
A. CLEANING	0.0	0.0	0.033	0.066	0.833	0.083	40	0.4	
B. SLEEVE INSERTION & EXPANSION	0.0	0.0	0.833	1.666	30	3.00	40	0.4	
C. BRAZING	0.0	0.0	0.200	0.400	0.4	0.04	40	0.4	
D. EXPLOSIVE WELDING	0.0	0.0	0.833	1.666	30	3.00	40	0.4	
E. TOTAL VARIABLE EXPOSURE PER 100 SLEEVES	0.0	0.0	1.899	3.8	61.23	6.123	160.0	1.60	11.523*

*per sleeve for 100 sleeve batch

B&W Sealable Sleeve

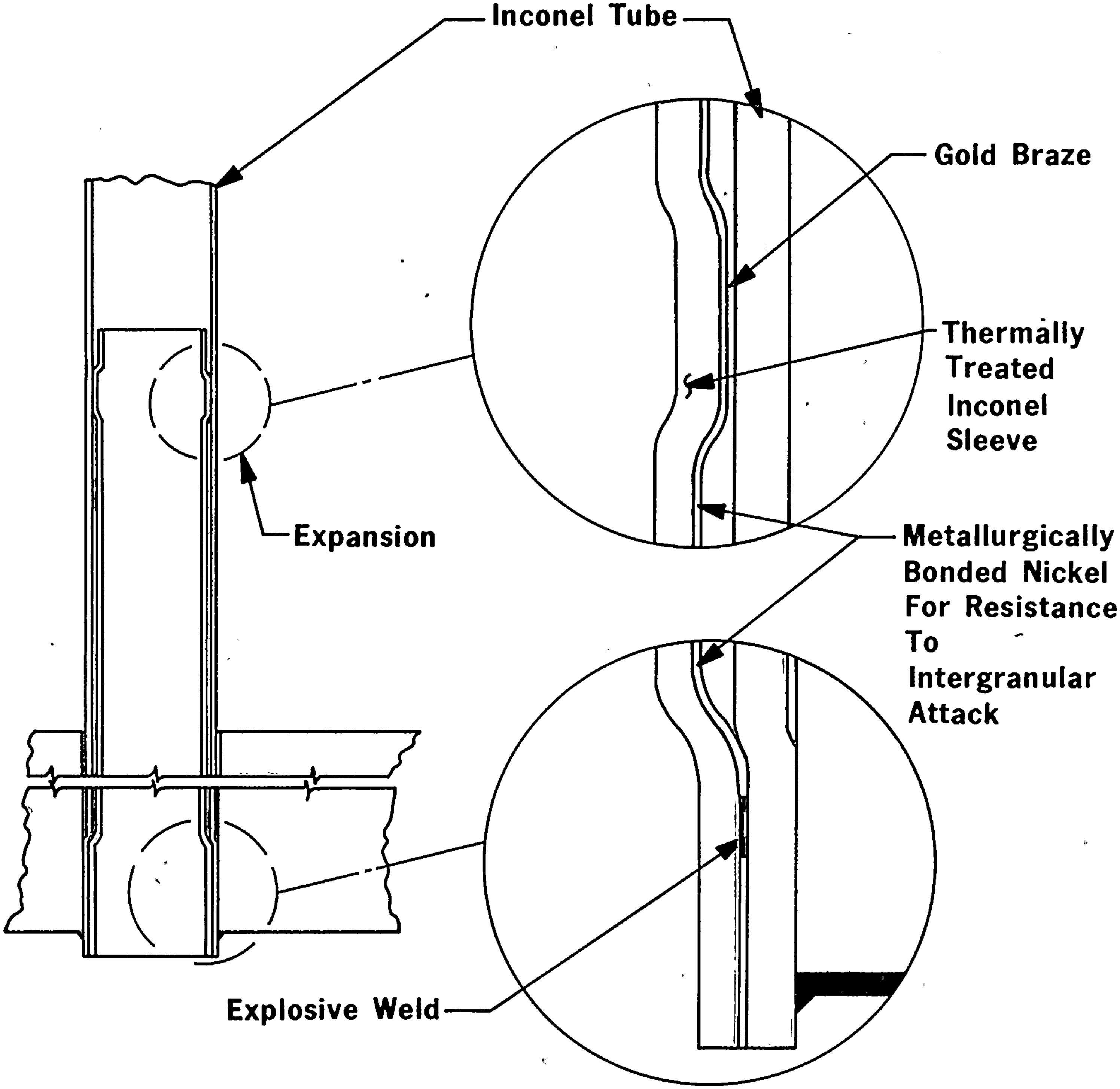
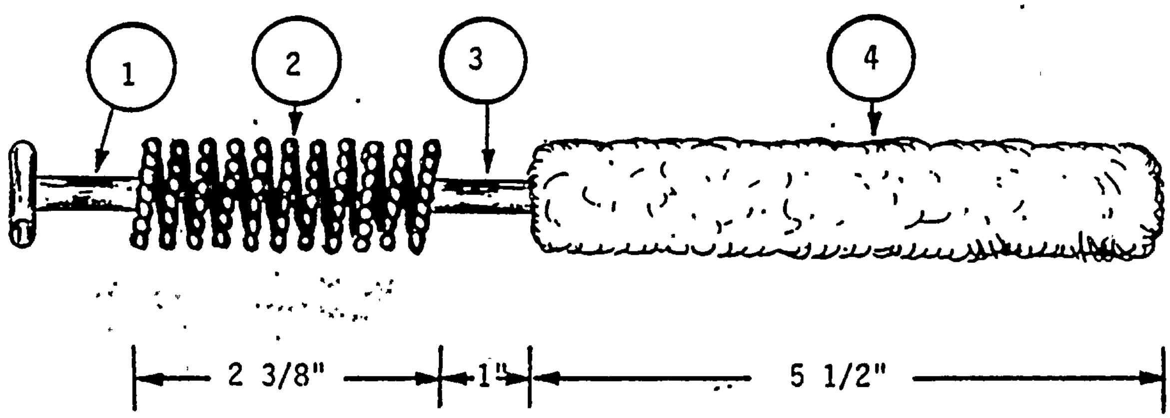


Figure 9-1

PROPRIETARY

FIGURE 9-2

COMBINATION HONE/SWAB TOOL



NOTES: 1. Drive shaft

2. Flexhone

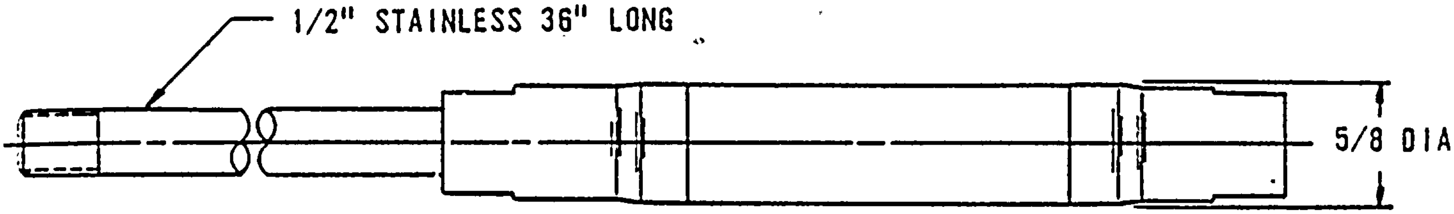
3. Coupling

4. Swab

PROPRIETARY

FIGURE 9-3

EXPLOSIVE EXPANSION CARTRIDGE



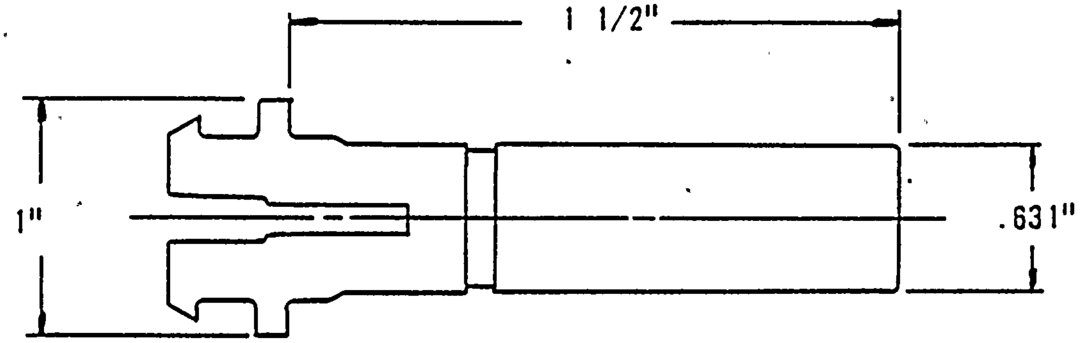
FUNCTIONAL DESCRIPTION:

1. IT CONTAINS THE DETONATOR AND A QUANTITY OF EXPLOSIVE CHARGE.
2. IT POSITIONS THE EXPLOSIVE CHARGE
3. IT IS REUSABLE PENDING CLEANING AND INSPECTION.
4. IT PROVIDES INTERFACE WITH THE REMOTE INSTALLATION TOOLING.

PROPRIETARY

FIGURE 9-4

EXPLOSIVE WELD CARTRIDGE



FUNCTIONAL DESCRIPTION:

1. IT LOCATES THE EXPLOSIVE CHARGE INSIDE THE SLEEVE.
2. IT IS SELF HOLDING WHEN INSERTED INSIDE THE SLEEVE.
3. IT PROVIDES A LOWER END CONFIGURATION FOR INTERFACE WITH THE INSERTION TOOLS.
4. IT CONTAINS THE DETONATOR FOR THE EXPLOSIVES.
5. IT CONTAINS EXPLOSIVES.
6. THE ENCAPSULATING MATERIALS SHATTER DURING THE EXPLOSIVE WELD AND ARE ACCEPTABLE FOR NUCLEAR USE.

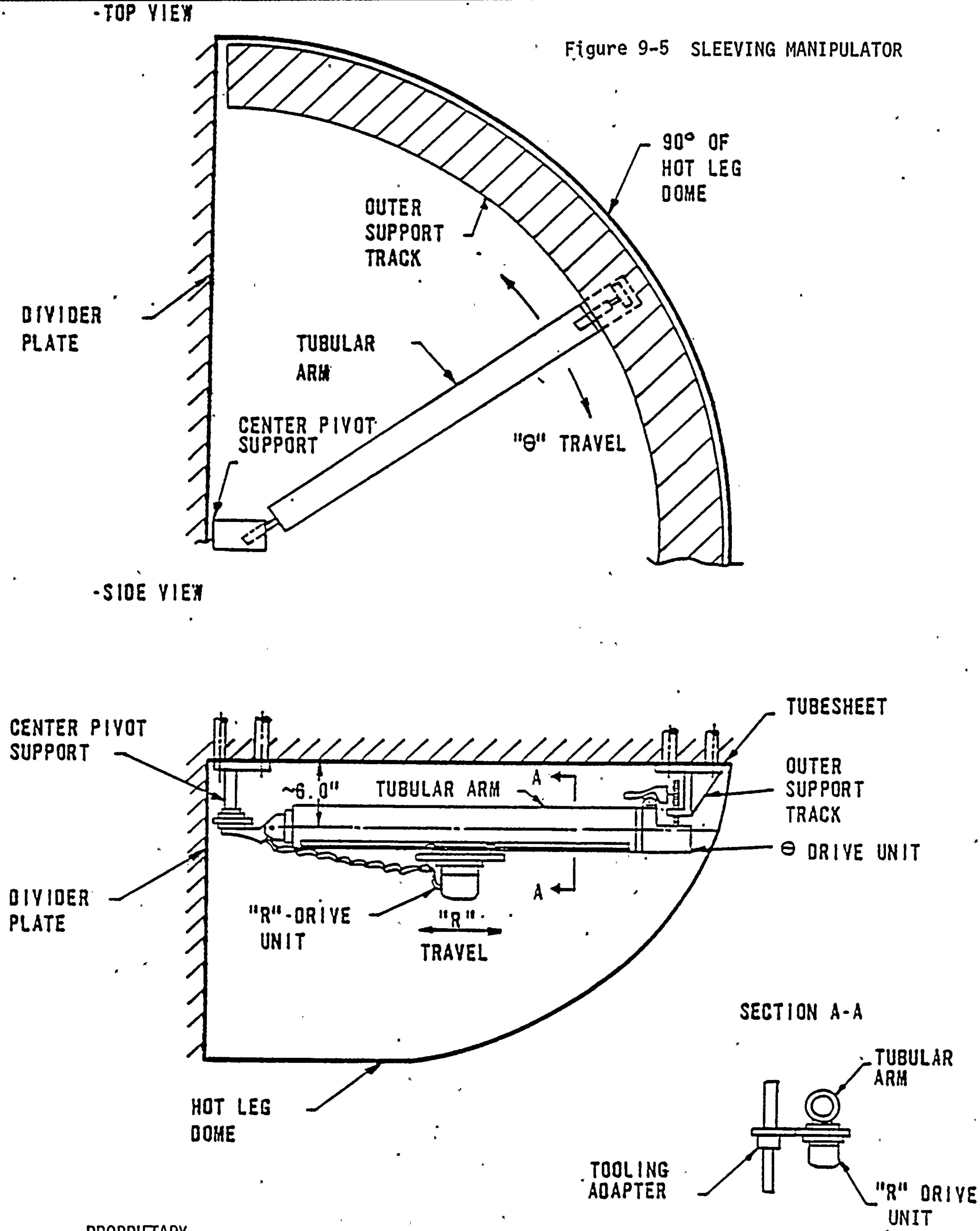
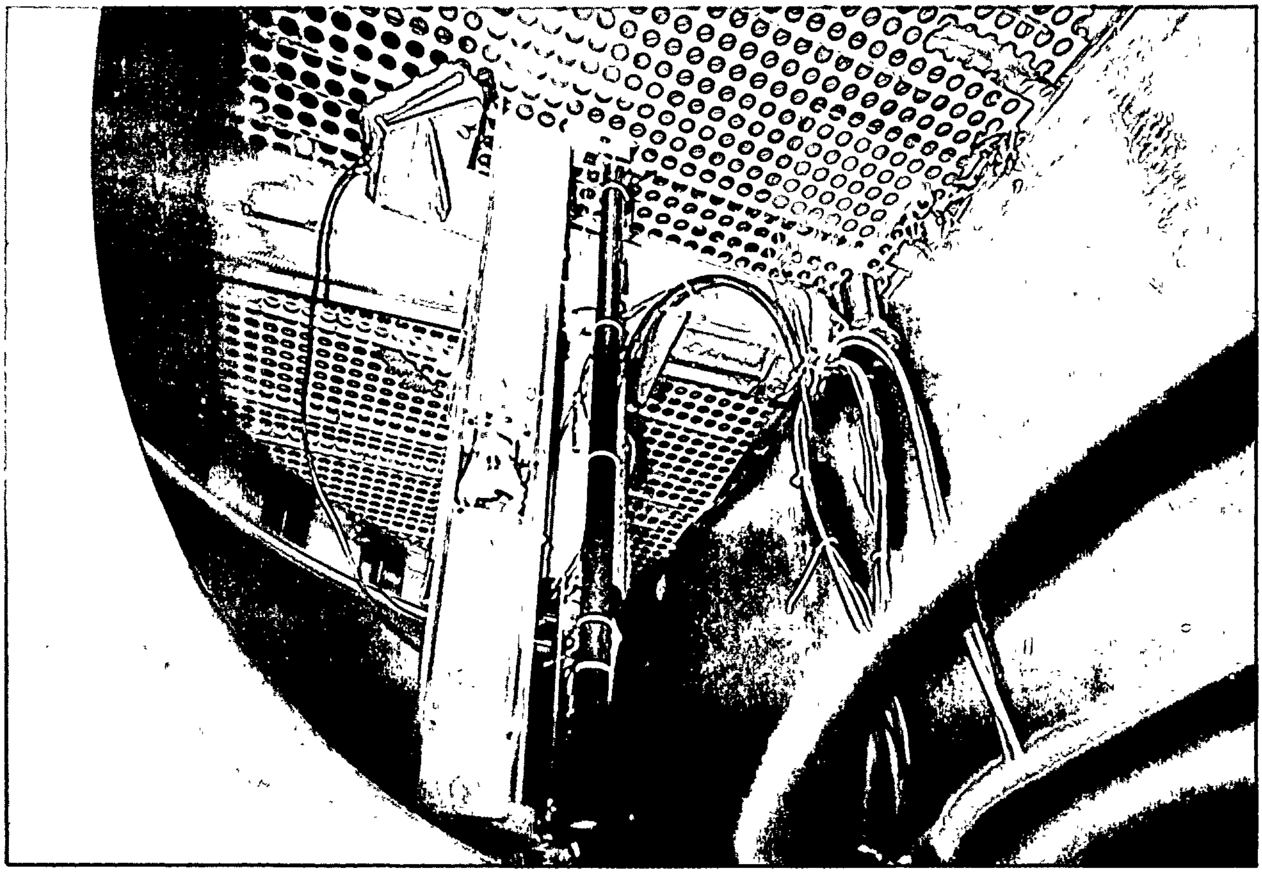


Figure 9-5 SLEEVING MANIPULATOR

PROPRIETARY

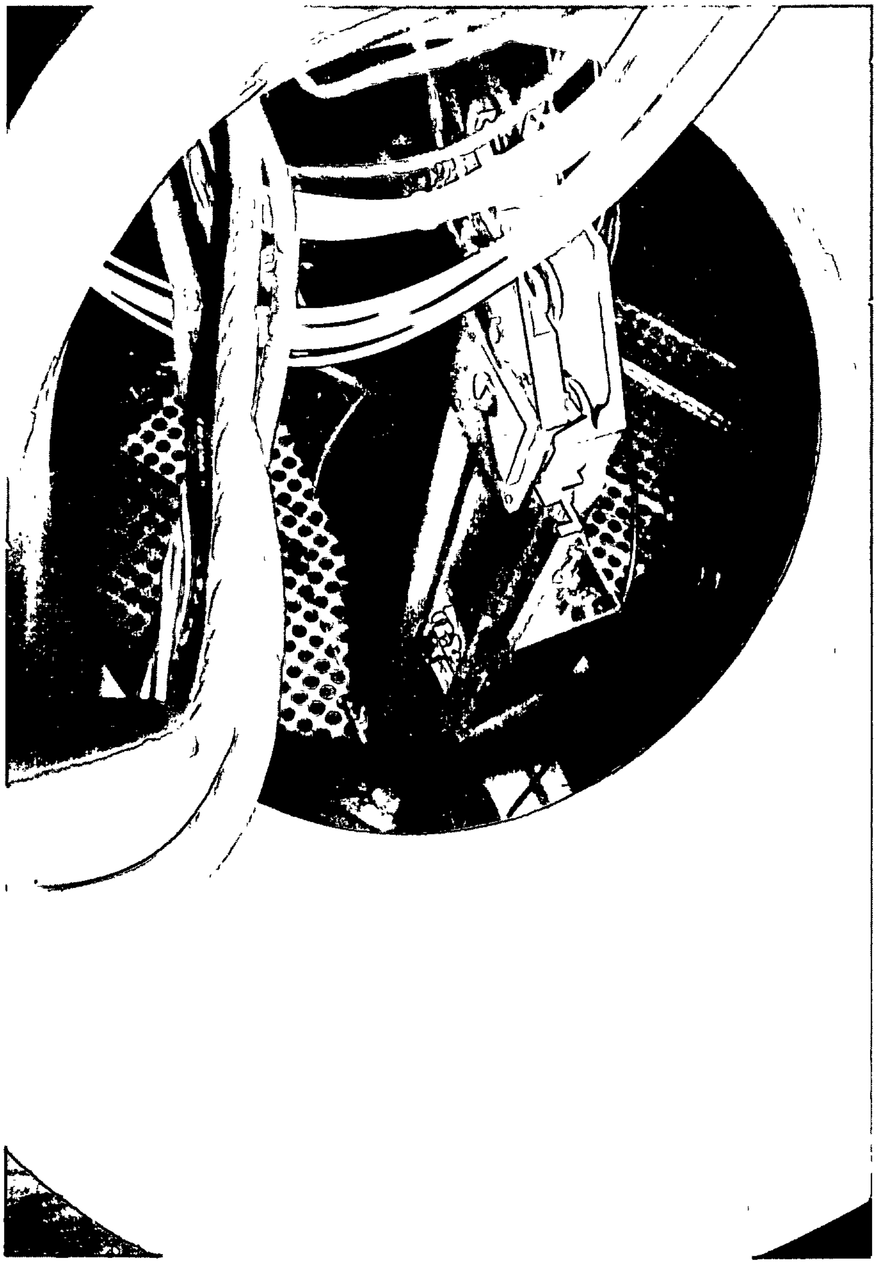


Sleeving Manipulator Arm and Radial Drive Unit with the Elevator Attached

Note the "V" groove adapter at the base of the elevator for rapid attachment of accessory tooling. The retractable fingers midway up the column are used to steady the sleeve or induction braze wand until the upper end has entered the tube or sleeve. A portion of the peripheral track is visible in the background.

FIGURE 9-6

PROPRIETARY

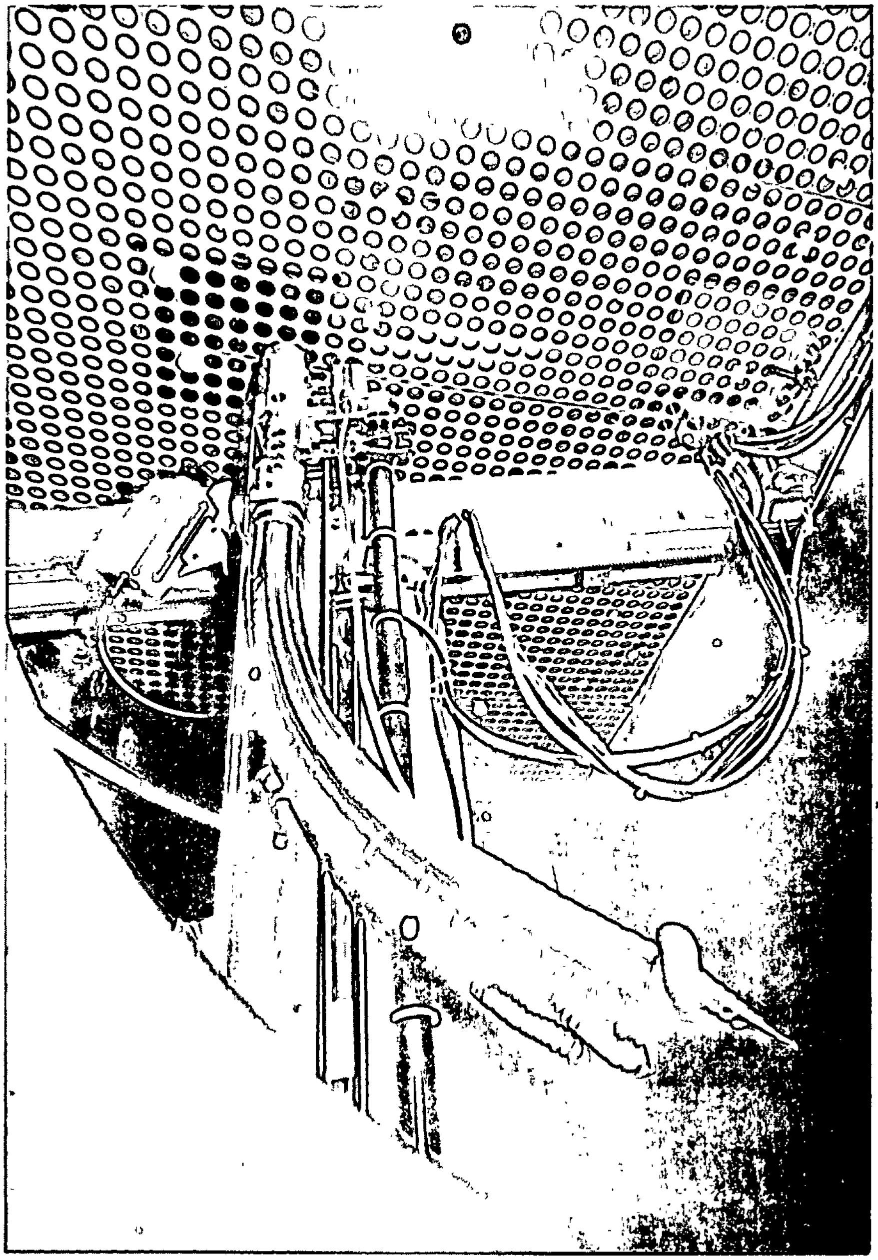


Another View of the Sleeving Manipulator Elevator as it Appears at the Manway Opening

Tool loading can be accomplished by reaching into the manway. With practice, visual observation is no longer needed.

FIGURE 9-7

PROPRIETARY

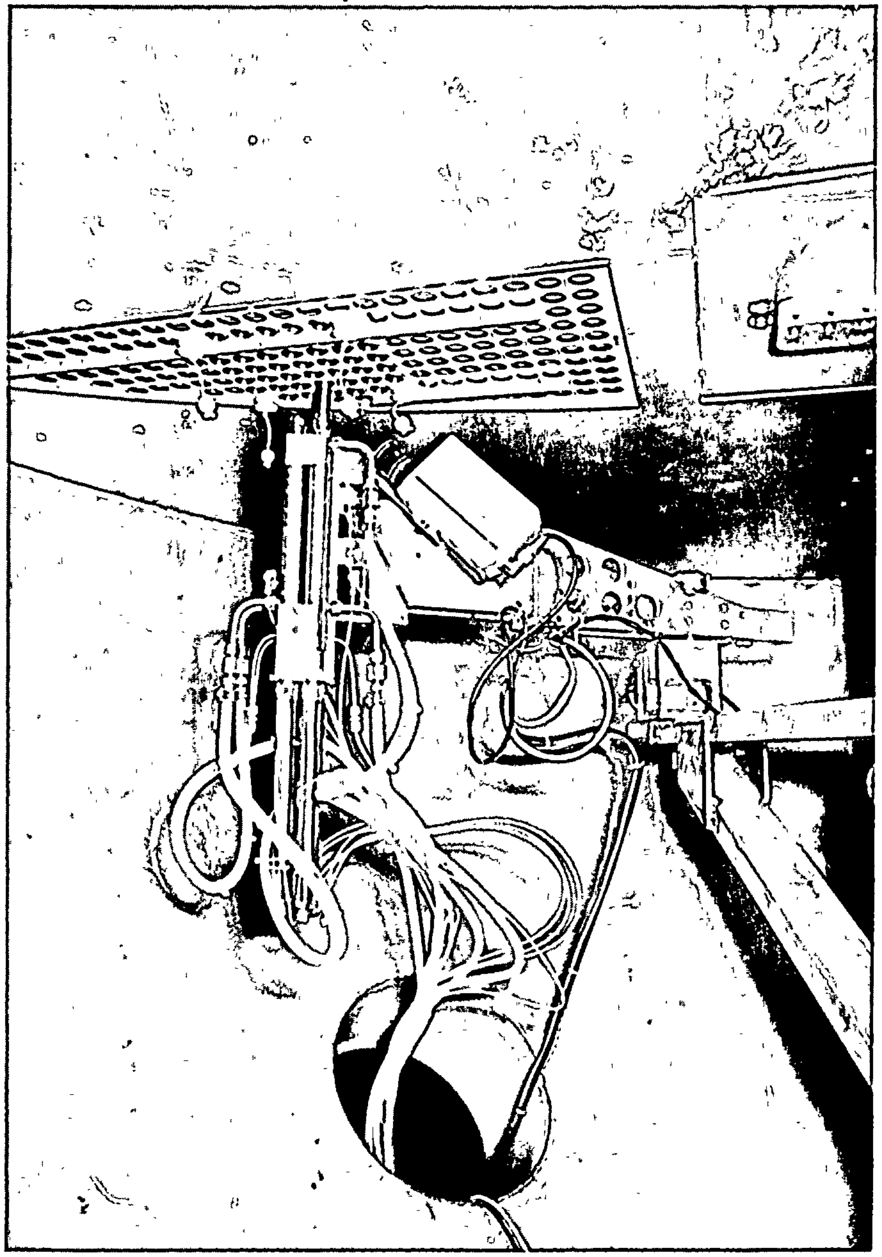


Tube Cleaning System Snorkel Positioned at the Tube End

The hone/swab assembly is changed outside and away from the manway opening after each cleaning operation. The snorkel end is indexed to the next tube to be cleaned during the changeout.

FIGURE 9-8

PROPRIETARY

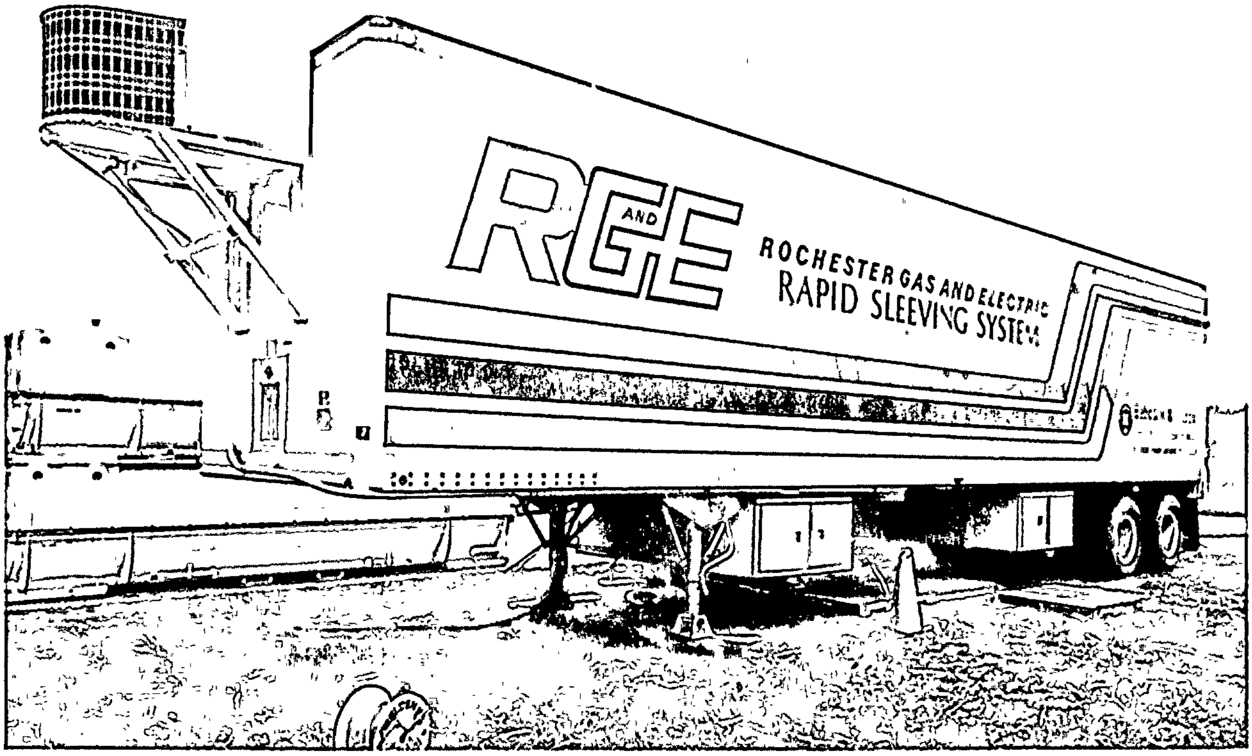


Purge System Manipulator and Plugs

The manipulator has a wrist movement in order to allow insertion of up to four plugs at once. The argon purge is controlled to each plug individually. This view shows one plug inserted, expanded, and ready to purge a tube that has a sleeve ready to braze in the other end.

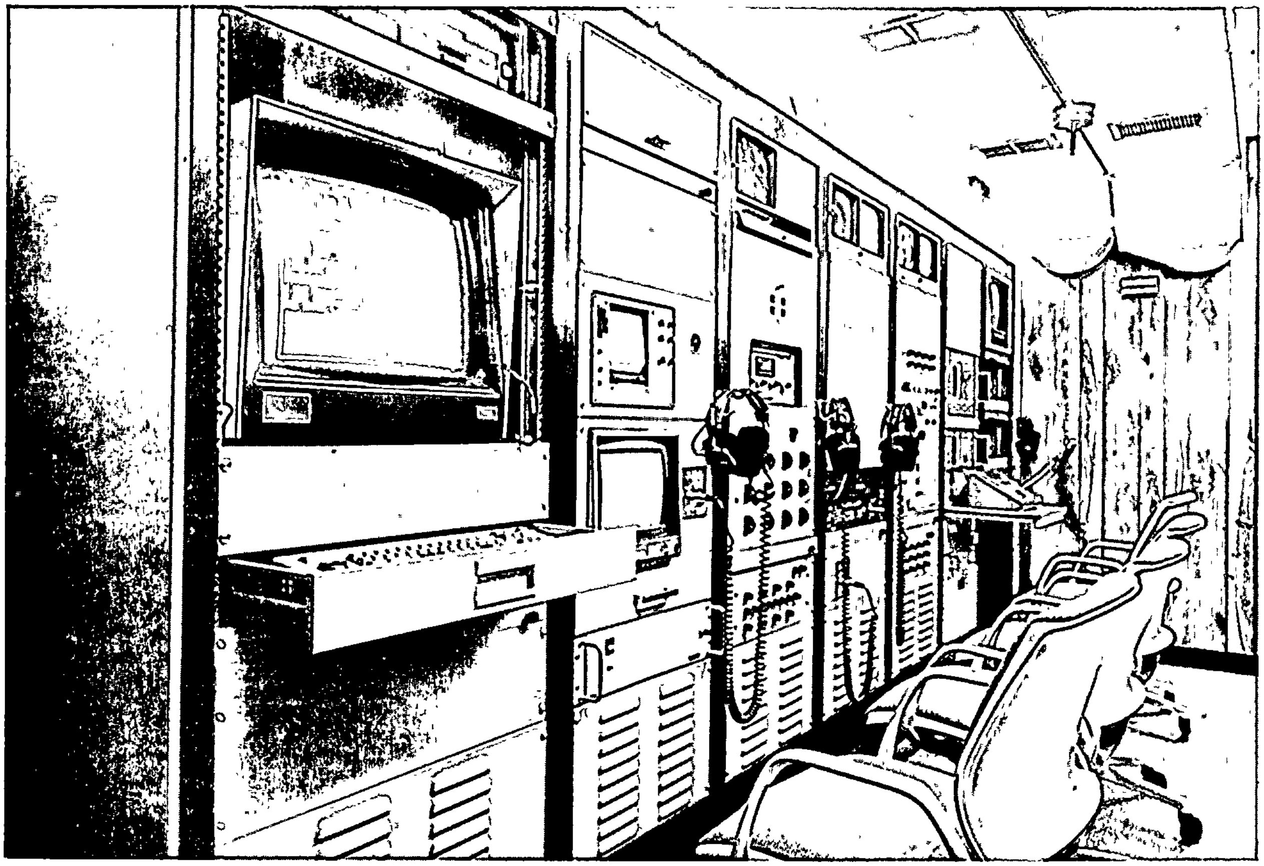
PROPRIETARY

FIGURE 9-9



Sleeve Tooling Control Trailer

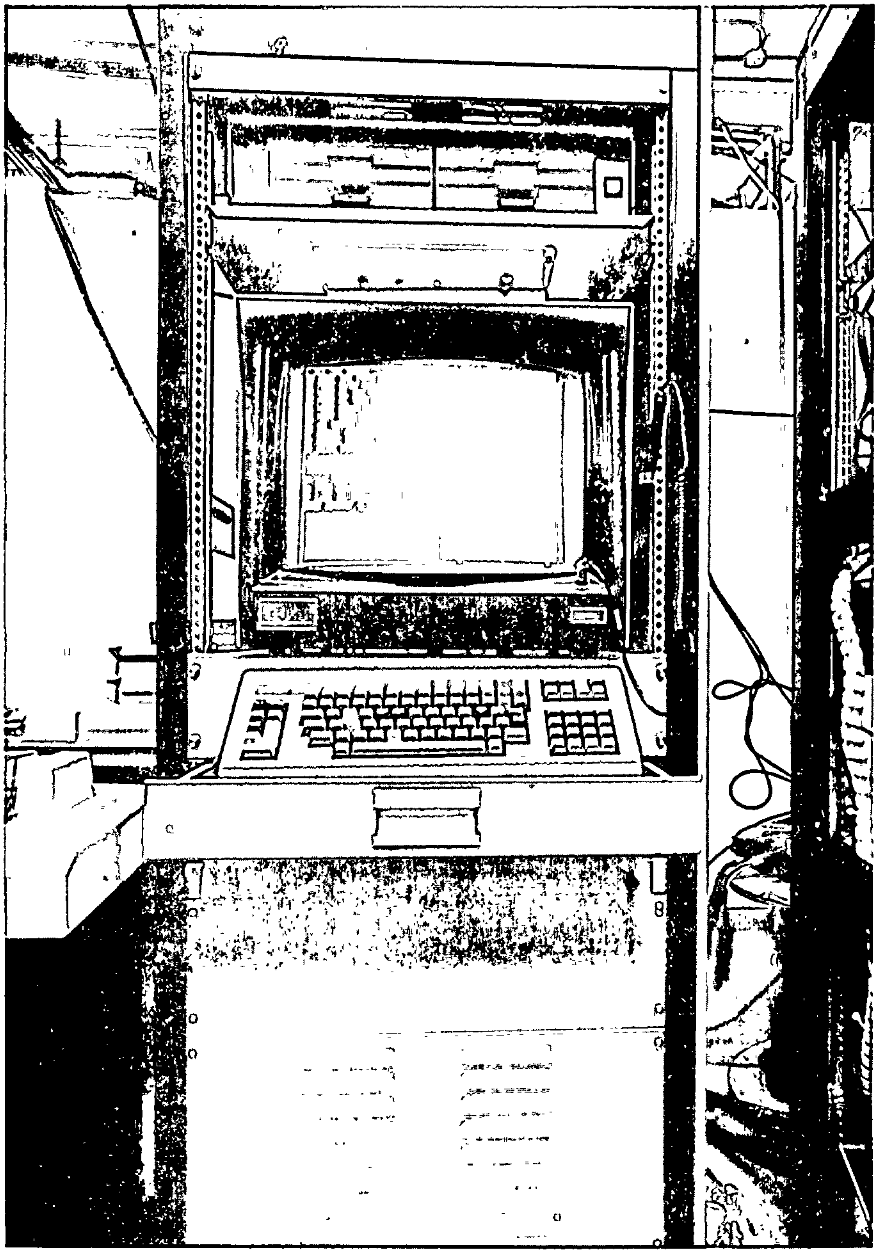
The trailer is complete with heat pump, self-leveling suspension system, and a fire smothering system.



One of the Two Control Consoles Contained in the Sleeve Control Trailer

The functions of the seven panels are described in the text.

FIGURE 9-11



Data Collection System Cabinet

The video screen contains a blown-up grid depicting a section of the tube sheet. This can be enlarged further to show a five-tube by five-tube area in the same space. The floppy disk drives are housed above the video display. Individual steps performed are inputted via the keyboard. Dates and times of accomplishment are automatically recorded. The current status of any tube contained on the grid is depicted by a colored block in the space corresponding to the tube. Each step in the process corresponds to a different color.

FIGURE 9-12

10.0 INSPECTABILITY

The pressure boundary in the steam generator is normally monitored by nondestructive examination (NDE) techniques. The guidelines established by ASME Section XI Division 1, Rules for Inservice Inspection of Nuclear Power Plant Components, the Code states that "Eddy current examination of heat exchanger tubing shall be conducted..." IWA-2233. These guidelines which comply with 10CFR50, Appendix B, provide calibration and equipment requirements in "...accordance with the provisions of Appendix IV" of the Code.

An ultrasonic inspection (UT) also has features that are valuable in inspecting sealable sleeves. This section presents the instrumentation to perform these inspections.

10.1 Eddy Current Inspection

The eddy current inspections provide both baseline and subsequent in-service data from which the integrity of the installed sealable sleeve, and the parent tube containing the sleeve can be determined. The pressure boundary consists of the sleeve, from the primary face of the tubesheet up to the lower edge of the lower braze ring, and the parent tube, from the lower edge of the lower braze ring extending upward.

10.1.1 Test Sleeve Eddy Current Inspections (PROPRIETARY)

A Non-Destructive Examination (NDE) system including eddy current techniques, probes and driver was used as follows for the inspection of the nickel plated test sleeves. The entire sleeve with the exception of the explosive weld area in the tubesheet was scanned using a 0.610 inch diameter conventional annular differential type probe. The probe was inserted into the proper tube/sleeve using the positioner and pulled from the tube/sleeve at approximately 0.5 feet per second using a hand pull. The information was obtained using both a Zetec MIZ-12 multifrequency eddy current instrument and an Automation Industries EM-3300 single frequency instrument. Data collected simultaneously at four frequencies using the MIZ-12 was stored on an 8-channel magnetic tape recorder. The frequencies selected were 50 khz, 100 khz, 300 khz, and 600 khz (all differential). The reason for using four separate frequencies was to concentrate the inspection at specific areas, namely, the sleeve itself, the tube behind the sleeve, and the tubesheet component, all in a single scan. The EM-3000 was used at 50 khz, low sensitivity to look at the braze/expansion region alone. This was to answer such questions as: Was the braze centered in the expansion, and has the gold braze material flowed out of the reservoirs into the annulus between sleeve and tube? The extent (percentage of tube wall and/or percentage of sleeve wall) of any detected flaws were to be estimated by calibration curves constructed after initial system calibration.

After scanning with the annular probe, an axial differential probe, with centering collars and spring loaded coils, was used to interrogate the braze/expansion region of the sleeve. The probe, in this case, was driven using the Zetec SM-6 probe driver, rotating the probe while withdrawing it axially, resulting in a helical scan. An approximate scan rate of 0.5 inch per minute and 12 rpm was used.

Again, a multifrequency scan was performed to allow simultaneous inspection of sleeve and tube. The frequencies were 100 khz absolute, 110 khz, 310 khz, and 610 khz, the latter three being differentrial. No calibration curves were used in this technique. Instead, a rough estimate of flow depth can be made by referring to calibration signals of flaws of known depth. Baseline inspection incorporated both the annular coil and axial differential coil techniques. Good data was obtained on which to base all subsequent inspections of the sleeved tubes. The data was collected and analyzed and no signification defects were detected.

During May 1981, a follow-on inspection was made of the five (5) previously installed nickel plated sleeves and a baseline inspection of the installed sixteen (16) co-extruded bimetallic sleeves. The follow-on and baseline inspections continued to use the annular coil and axial differential techniques as previously described. However, improved probes were used for both techniques as necessitated by the use of the co-extruded bimetallic sleeve material. A high penetration, magnetic saturation, annular differential eddy current probe was used to inspect the region of the sleeved tube between the explosive weld and braze/expansion. The same equipment and frequencies were used. No sleeve degradation was noted. (PROPRIETARY)

10.1.2 Rapid Sleeving Eddy Current Inspection

The objective of the Rapid Sleeving Eddy Current inspection system is to provide an eddy current system to support examination of large scale sleeve installations at GINNA. The strategy is to utilize lessons learned from the May 1981 GINNA outage to improve the eddy current technique, upgrade the probe designs, and improve the system deployability.

System Description

This eddy current system consists of the following components:

(1) Multi-frequency generator, Zetec MIZ-12
(2) Eddy current probe (multi-coil)
(3) Storage oscilloscope
(4) Tape recorder (eight channel)
(5) Strip chart recorder
(6) Probe driver (D.C. variable speed motor, 15 in/min)
(7) Manipulator to position probe, calibration stand and specimen holders
(8) Video and communication system
(9) Cables, standard magnetic tape, and the like to support all equipment during inspection.

The eddy current data is recorded on standard magnetic tape by an eight channel tape recorder with voice log capability. The horizontal and vertical components of one channel are recorded on a strip chart.

A specially modified eddy current instrument will be used to drive the coils in the probe. These modifications were necessary to operate the multi-coil probe at frequencies of 50 khz, 100 khz, 300 khz, and 600 khz (all differential). While the coils are driven independently, they still provide the real-time vector addition of frequencies necessary to suppress the residual response that can be introduced by the increased sleeve diameter at the upper seal weld.

The entire circumference of a sleeve cannot be completely inspected in one inspection pass. Therefore, the examination is performed in steps by first inserting the probe,

rotating it 45 degrees, and then withdrawing it. The probe is inserted and extracted at approximately 15 inches/min. by a driver with a D.C. variable speed motor. The multi-coil probe is designed to detect ASME XI-defined defects in the tube sleeve assembly while being able to accommodate for the:

- o Change in sleeve diameters
- o Presence of the highly-conductive gold alloy in the weld
- o Bimetallic sleeve.

A large change in sleeve diameter occurs at the explosive expansion or upper end attachment. The change in probe "fill-factor" caused by this diameter increase affects the output of the eddy current instrument because the flux density generated in the sleeve decreases as the distance of the coil from the ID of the sleeve increases. This large amplitude expansion signal potentially could mask defects which may be present in the diameter transition region. This situation was remedied by using a special multi-coil probe.

The presence of the highly-conductive gold braze alloy and braze material reservoirs machined into the outside surface of the sleeve are additional variables which must be addressed. Since the eddy current test is an electromagnetic technique based on the electrical properties of the test material, potential flaws in the braze regions of the pressure boundary may be hidden by the response of the braze material.
The differential nature of the probe allows optimum inspection through the braze/expansion region. As the probe enters this

region, the coils use one another as a reference to suppress the response to the expansion, the highly conductive gold braze alloy, and the two reservoirs containing the braze alloy. This inspection can detect whether or not the gold braze material has flowed out of the reservoirs into the annulus between the sleeve and the tube.

Another variable considered is the bimetallic composition of the sealable sleeve which is fabricated by co-extruding nickel onto an Inconel 600 base. Nickel, a ferromagnetic material, not only causes spurious indications due to variations in permeability but also reduces the depth of penetration of the eddy current. Magnetic bias is fabricated into the probe to counteract the effects of the ferromagnetic nickel cladding on the sleeve O.D. The strong magnetic field applied by the magnet contained in the probe saturates the nickel cladding and causes the magnetic domains in the material to position themselves in the north-south direction of the field. This orientation results in increased penetration of the eddy currents and thus reduces the spurious indications caused by variations in permeability. (PROPRIETARY)

Calibration and Sensitivity

The calibration standards used with this inspection technique contain flat-bottomed holes on both the sleeve and tube outside dismeters representing potential flaws in the free span of a sleeved tube. Additional standards contain representative braze/expansion joints with flat-bottomed holes on the sleeve and tube O.D.s, both in the center of the braze region and at the transition of the expansion. Paragraph IV-3200 of ASME Section XI code provides calibration standard sizes for the eddy current inspection of a tube. Installing a sleeve in a tube presents two boundaries for inspection. The eddy current instrumentaion can easily detect flaws

in the sleeve and also can detect flaws in the steam generator tube behind the sleeve. The holes, partial penetration holes, and grooves listed below are used in calibrating the eddy current system:

(1) Through-wall drilled hole (0.052 inch diameter for 3/4 inch tube),

(2) Flat-bottomed drilled holes of the listed diameters and partial penetration from the outer tube wall surface,

Hole Diameters, In.	Penetration Through Wall, %
5/64	80
7/64	60
3/16	40

(3) Four flat-bottomed drilled holes 3/16 inch diameter spaced 90 degrees apart around the tube circumference, 20% through the tube wall from the outer wall surface,

(4) Circumferential grooves for the inner and outer surface,

Surface	Width, Groove Inches	Penetration Through Wall, %
Inner	1/16	20
Outer	1/8	10

The inspection can detect loss-of-metal in the sleeve parent tube of 20% of the wall and 3/16 inch in diameter and loss-of-metal in the surrounding tube in the braze/expansion region of 40% of the wall and 3/16 inch in diameter. Additional discontinuities have been evaluated and can be characterized by the eddy current inspection as general loss of metal including both inside and outside surfaces in the sleeve, localized conductivity changes in the sleeve (indicative of IGA), wastage and cracking in the sleeve, damage to the sleeve during installation, and gross loss-of-metal in the parent tube.

Operation

The equipment establishes a system that is fast, complete, and remotely operated (cable lengths of 400-500 feet) so that the radiation exposure to test personnel is minimized. A manipulator positions the probe over the tube to be inspected. A flexible, braided steel conduit connects the manipulator to the probe driver which carries the in-line calibration standard holders for remotely controlled calibration checks. A video and communication system supports the remote operation and extension cabling permits the inspection equipment to be operated from outside the containment building.

10.2 Ultrasonic Inspection System

Objective

The objective of this ultrasonic examination system is to examine the integrity of the braze joint between the sleeve and the parent tube. The system can detect the extent of bonding and quantify defects (porosity) found in the brazed joint, based on porosity and a potential leak path through that brazed joint.

System Description (PROPRIETARY)

The UT system comprises three components:

- o A computer control console outside the containment
- o A console inside the containment
- o A scanner

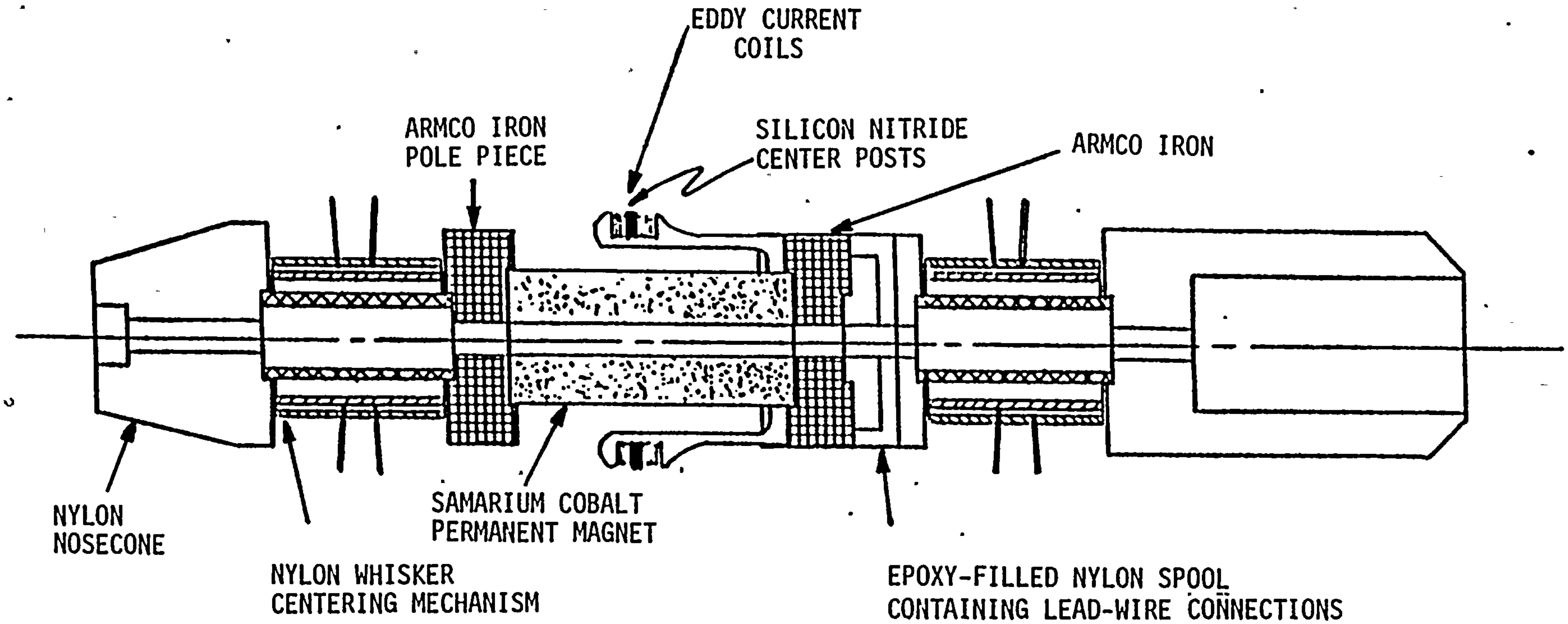
The computer control console contains a Krautkramer-Branson Model KB-6000 two channel, computer controlled, ultrasonic instrument, Ultrasonic International Inc. Controller/Data Analyzer, floppy disc storage unit, graphics display unit, and a keyboard with monitor. This console interracts with the containment console which contains a motion control driver microprocessor and two stepping motor translators. Also included in this console is a couplant delivery and retrieval system, a system status display, transducer pre-amplifier power supply and a video power supply. The computer control console is connected to the inside console inside the containment by a 575 ft. cable bundle. The scanner is connected by a 25 ft. cable bundle to the console inside the containment. The scanner delivers a round wand, with a specially designed ultrasonic transducer probe, up into the sleeved tube, a maximum of 36 inches. The wand is driven in a linear vertical (Y) and radial (Ø) direction by two 300 in.-oz. stepping motors to facilitate the desired scan pattern. The couplant delivery system supplies the scanner with the desired amount of couplant to flood the annulus around the probe. The linear (Y) drive system has a clutch built into its drive assembly so that should the probe sense any resistance during its insertion, whether inside the sleeve or at the tube sheet, the wand will stop and then prevent any damage to the scanner. A closed-circuit TV camera is mounted on the scanner to monitor the ultrasonic probe during its insertion into the sleeve. A calibration standard is attached on top of the scanner so before the probe enters the sleeve, the ultrasonic calibration is checked and verified and the probe's starting reference position is also verifed. (PROPRIETARY)

Calibration and Sensitivity

The calibration standard consists of a mockup of the tube-sleeve braze joint thickness with a 0.020 inch diameter flat bottomed hole machined into the standard at the braze bond interface dimension. Based on this calibration with gating the signal response at the 20% level of the calibrated signal amplitude, it is estimated that a defect area as low as $7.9(10)^{-5}$ square inches can be readily detected.

Operation (PROPRIETARY)

The UT system can be either operated totally by its computer or manually controlled at three different locations: (1) computer keyboard, (2) terminal printer keyboard, or (3) a hand held key pad from inside containment. The computer programs are stored on floppy disks that calibrate the ultrasonic instrument, program the motion control driver microprocessor, and supply the operator with a menu of sub-routines to establish the parameters of the inspection. Data is acquired by the computer. All raw data is stored on the floppy disks for storage and easy retrieval and display. During actual examination, the graphic display unit presents a C-scan at the sensitivity desired of the area being examined. Additional presentations generated by the system are a modified B-scan showing a cross-section view of the joint through any desired scan path, an isometric C-scan showing response amplitudes vs the Y and Ø motions, and hard data display. These presentations can also be printed on hard copy via the terminal printer.



CROSS SECTIONAL VIEW OF FOUR-COIL EDDY CURRENT PROBE

PROPRIETARY

FIGURE 10-1

11.0 TECHNICAL SPECIFICATIONS

The Technical Specifications and their bases have been reviewed to determine whether or not they must be changed if steam generator sleeves are used. Technical Specification 3.1.5 establishes a limit on primary or secondary leakage of 0.1 gpm. This limit, reviewed and approved by the NRC in Amendment Number 16 and transmitted on May 14, 1975, ensures the integrity of the steam generator tubes under postulated accident conditions. Comparing the pressure stresses in a steam generator tube with those in a sleeve demonstrates that a sleeve can withstand the differential pressures better than a steam generator tube. Thus, a sleeve with a through-wall crack superimposed on wastage will perform as well as, or better than, a steam generator tube with a through-wall crack superimposed upon wastage of the same magnitude (in terms of percent wastage). Therefore, since in either case the through-wall crack length is monitored by assessing primary to secondary sytem leakage, the current Technical Specification and its bases remain valid for sleeve tubes.

Specification 4.2 governs the inservice inspection of steam generator tubes by referencing to the Ginna Station Inservice Inspection Program. The Inservice Inspection Program is being revised to allow the sleeving of steam generator tubes in lieu of plugging. This document is not a part of the plant Technical Specifications and may be revised pursuant to 10CFR 50.59. Indeed, changes and subsequent implementation pursuant to 10CFR 50.59 may, on some occasions, be required to conform to 10CFR 50.55a.