MONTICELLO

APPENDIX H

REACTOR PRESSURE VESSEL DESIGN SUMMARY REPORT

MONTICELLO NUCLEAR GENERATING PLANT
MONTICELLO, MINNESOTA
UNIT 1

NOTE: The effects of increasing reactor power to 2004 MWt were evaluated in Task Report T0302, Reactor Vessel Integrity - Stress and Fatigue Evaluation, to ensure that the reactor vessel components continue to comply with the existing structural requirements of the ASME Section III Boiler and Pressure Vessel Code. Reference "Task Report T0302, Reactor Vessel Integrity-Stress and Fatigue Evaluation," (Monticello calculation number 11-223), for further information. 01101248

MONTICELLO

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DESIGN AND FABRICATION REQUIREMENTS

The Monticello reactor vessel was designed, fabricated, inspected, and tested in accordance with the American Society of Mechanical Engineers Boiler and Pressure Vessel Code Section III, Nuclear Vessels 1965 Edition and Addenda to and including Summer 1966 Addenda, and the following additions:

1. ASME SA533 plate and Inconel material per Summer 1967 Addenda.
2. Main closure flange material per Code Case 1332-3.
3. Studs and nuts material for main closure flanges per Code Case 1335-2.
4. Main closure flange and stud shank transition radius per Code Case 1366.
5. Bearing stresses for stabilizer brackets and coefficients of thermal expansion per Winter 1967 Addenda.
6. Magnetic particle and liquid penetrant examination per Winter 1966 Addenda.

The date of the contract between the Buyer, General Electric Company, Atomic Power Equipment Department, San Jose, California and the Seller, Chicago Bridge and Iron Company, San Francisco, California, was July 18, 1966. There are no deviations to the formal code throughout the design, fabrication, inspection and testing of the reactor vessel.

Design fabrication, inspection, and test requirements in addition to those required by the B&PV code were required by the Buyer's vessel purchase specification 21A1112 (Exhibit 1). These include but are not limited to the following pertinent inspections and/or tests:

1. Established specific maximum nil ductility transition temperatures for the main closure flanges and the shell and head materials connecting to these flanges (+10°F NDT temperature) and elsewhere (+40°F NDT temperature).
2. A fabrication test program on vessel shell material which included testing of large size tensile specimens (80% of the vessel wall thickness in diameter) both plain and welded samples. (See Exhibit 3).
3. Provisions are made for determining the effects of nuclear radiation upon the reactor vessel structural materials by supplying specimens of the vessel material to be exposed to the core irradiation at the vessel wall inside of the vessel.

Pertinent certifications are contained in Exhibit 2, Manufacturer's Data Report and Vessel Certification, Chicago Bridge & Iron Company.

The summary of results of the detailed stress analysis is contained in Exhibit 4.

Plans for the vessel fabrication and assembly were described in Amendment 2 to the FDSAR, "Design Fabrication and Erection of the Reactor Vessel." Actual fabrication and assembly was in accord with Section IV of Amendment 2 except for minor modifications as listed in Exhibit 5 of this report.

The GE quality control of the reactor vessel was essentially as described by General Electric Quality Control Plan, Section IV of Amendment 2 to the FDSAR, except the Domestic Turnkey Projects organization of General Electric Co. also made an independent QC audit.

A detailed seismic analysis of the Reactor Pressure Vessel was prepared by John Blume & Associates and was included in Appendix A along with other seismic analyses.

In 1977, repairs were made to the reactor pressure vessel feedwater nozzles and safe ends to minimize damage to the feedwater nozzles due to thermal cycling. The repairs consisted of removing cladding from the nozzle blend radius and bore and the installation of a feedwater sparger interference fit thermal sleeve with a piston ring seal. These design changes invalidated the "Summary of Stress Analysis for the feedwater Nozzles" shown on page 4-14 of Exhibit 4. Details of this repair and design are contained in Exhibit 7.

Also in 1977, a design change modified the CRD return line because of its susceptibility to intergranular stress corrosion cracking. The 3" CRD return line and the reactor vessel nozzle safe-end forging were removed and the nozzle was capped using a 4" diameter schedule 120 pipe cap. This design change eliminated the imposed mechanical loading for the nozzle, creating a much less severe condition than the nozzle was originally designed for. As a result of this modification, the "Summary of Stress Analysis for the 3" CRDHSR Nozzle" shown on page 4-18 of Exhibit 4, is invalidated. Details of the modification and new stress analyses are contained in design change 77M069.

In 1981, new feedwater nozzle safe ends featuring a tuning fork design with a welded in thermal sleeve were installed and a section of piping upstream of each nozzle was replaced with piping of a different material. These modifications were performed to provide a significant reduction in thermal cycling of the feedwater nozzle area. The new stress analyses that replaced the "Summary of Stress Analysis for the Feedwater Nozzle" shown on page 4-14 of Exhibit 4, are contained in Exhibit 8 and Exhibit 9.

In 1984 several modifications were incorporated to provide greater resistance to intergranular stress corrosion cracking.

The core differential pressure and standby liquid control safe end was replaced using a safe end of similar design, but with different materials. The new stress analyses are contained in General Electric Stress Report No. 23A4115, included in Design Change No. 83Z049C.

The jet pump instrumentation safe end and penetration seal was replaced with the jet pump instrumentation nozzle penetration seal, using low carbon 316 to replace the original ASTM A508 Class II material. The new stress analyses are contained in General Electric Stress Report No. 23A1939, also included in Design Change No. 83Z049C.

The core differential pressure and standby liquid control, and the jet pump instrumentation modifications invalidated the "Summary of Stress Analysis for Core Differential Pressure and Liquid Control Nozzle, Head Cooling Spray and Instrumentation Nozzles, Vent Nozzle, Instrumentation Nozzles, Jet Pump Instrumentation Nozzles, Drain Nozzle, High Pressure Seal Leak Detector Nozzle and Low Pressure Seal Leak Detector Nozzle" shown on page 4-28 of Exhibit 4.

Also, in 1984, a corrosion resistant cladding overlay was applied to the inside diameter of the RV head vent nozzle and RV head cooling spray and instrumentation nozzles. The weld overlay of 308L isolated the IGSCC susceptible existing weld butter located in the weld residual stress area from the reactor coolant. As documented in General Electric Stress Report No. 23A4280, part of Design Change No. 84Z068, stress calculations performed originally at this location are still valid.

The recirculation inlet and outlet nozzles were both modified during the 1984 outage. General Electric Stress Report No. 23A1627, part of Design Change No. 83Z049A, documents the analysis of the redesign and replacement of the recirculation inlet nozzle safe end and thermal sleeve, including the attachment weld and the weld overlay to the recirculation inlet nozzle. This design change invalidated the "Summary of Stress Analysis for Recirculation Inlet Nozzle" shown on page 4-22 of Exhibit 4.

Bechtel Stress Report No. SR-10040-SS2 (Rev. 3), also part of Design Change No. 83Z049A, documents the analysis of the replacement of the recirculation outlet nozzle safe end fitting, a forged and machined component made of SA 358 Type 316 stainless steel. The "Summary of Stress Analysis in Recirculation Outlet" shown on page 4-24 of Exhibit 4 has been invalidated by this change.

In 1986, new core spray safe ends featuring a tuning fork design with a thermal sleeve were installed along with a section of piping upstream at each nozzle. This modification was performed to minimize the chance of IGSCC from occurring in the Core Spray System. The new stress analyses is documented by Bechtel Document 301-P-5.

Also in 1986, the CRD return nozzle, previously capped in 1977, was again modified. The purpose of the modification was to remove that portion of the existing weld butter layer susceptible to IGSCC, and re-clad the weld prep area with corrosion resistant cladding and install a new nozzle cap. General Electric Stress Report No. 23A5553, included as part of Design Change No. 86Z016, documents the analysis.

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EXHIBIT 1

REACTOR PRESSURE VESSEL PURCHASE SPECIFICATION 21A-1112

GENERAL ELECTRIC
NUCLEAR ENERGY DIVISION

Document No. 21A1112, Rev. 6
General Electric Class

TRANSMITTAL

PROJECT(S) MONTICELLO

TITLE OF DOCUMENT REACTOR PRESSURE VESSES

TYPE OF DOCUMENT:
[X] PURCHASE SPECIFICATION
[] SYSTEM DESIGN SPECIFICATION
[] INSTALLATION SPECIFICATION
[]

REPLACES DOCUMENT NO.

PIPING OR COOLING SYSTEM INVOLVED

RESPONSIBLE ENGINEER DR HEISING ISSUED BY JA MAST DATE MAR - 5 1969

REFERENCES

MASTER PARTS LIST (MPL) NOS.

SPECIFICATIONS 21A9821 - Stud Tensioner
21A1050 - Std. Requirements for Reactor Servicing Tools

DRAWINGS
107C5305 - Preparation of Nozzles
885D911 - Bolting
886D482 - Reactor Vessel
117B1549 - Charpy Impact Specimen
117B1550 - 1/4" Tensile Test Specimen
731E678 - Vessel As-Built Dimensions

REVISION RECORD

REVISED PER (~~ECA~~, ECN, ~~ETC~~.) #960

SHEETS AFFECTED 16 - 21 and Attachment E REVISION IDENTIFIED WITH ♠

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GENERAL ELECTRIC
ATOMIC POWER EQUIPMENT DEPARTMENT

PURCHASE SPECIFICATION

SPECIAL PROJECT
MONTICELLO
SPEC. NO. 21A1112 REV. NO. 6
SH NO. 1 CONT ON SHEET 2

TITLE
REACTOR PRESSURE VESSEL

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BY:	ISSUED:
DR Heising DR HEISING 3-4-69	JA Mast JA MAST 3/6/69

GENERAL ELECTRIC

ATOMIC POWER EQUIPMENT DEPARTMENT

PURCHASE SPECIFICATION

1.0 SCOPE

1.1 This specification defines the engineering requirements of the equipment specified herein.

1.2 The work done by the Seller in accordance with this specification shall include all necessary design, development, analysis, drawings, evaluation of materials and fabrication methods, shop fabrication, shipment, field erection, inspection, and testing.

2.0 RESPONSIBILITY

The Seller shall accept full responsibility for his work and for compliance with this specification. Review or approval of drawings, procedures, data or specifications by the Buyer with regard to general design and controlling dimensions does not constitute acceptance of any designs, materials or equipment which will not fulfill the functional or performance requirements established by the purchase contract.

3.0 GENERAL DESCRIPTION

3.1 The reactor vessel will be used as a pressure container supporting the steam generating core in the Monticello Nuclear Power Station to be located near Monticello, Minnesota.

3.2 The equipment to be furnished in accordance with this specification shall be one reactor pressure vessel assembly with a removable head and nozzles and certain internal support structures, arranged as shown on Drawing 886D482 complete with:

3.2.1 Attachments for thermal insulation, vessel and core supports, brackets or legs for lifting and handling of the vessel head, and mounts for outside surface thermocouples.

3.2.2 One set of necessary special tools required to remove and replace the reactor vessel head. The set of tools shall include: four hydraulic stud tensioners, stud elongation measuring device, stud and nut wrenches, one set of stud thread protectors, three head guide caps, one bushing wrench, one stud sling. Stud tensioners shall be in accordance with Specification 21A9821 and shall include a lifting device that properly spaces the tensioners over the bolt circle.

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PURCHASE SPECIFICATION

SPEC. NO. 21A1112 REV. NO. 6
SH NO. 3 CONT ON SHEET 4

3.2.3 One set of necessary special tools required to install and remove the reactor vessel head seals with manual contact. This set of tools shall include a protective cover for the reactor vessel shell flange seal surface.

3.2.4 Metal boxes for the hand tools. Boxes shall be suitable for handling with a crane and/or fork lift truck.

3.2.5 One lot of reactor vessel material test plate and material test specimens in accordance with Attachment B.

3.2.6 Shipping skids for those portions of the Reactor Vessel which are shop fabricated.

4.0 CODES

4.1 The reactor vessel shall be designed, fabricated, inspected, tested and stamped in accordance with the American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section III, applicable requirements for Class A Vessels as defined therein, interpretations of the ASME Boiler and Pressure Vessel Code, and all laws, rules and regulations of the State of Minnesota in effect on the date of the contract.

4.2 Deviations from the applicable codes or regulations shall be avoided. Where a conflict exists among the codes or regulations, the Seller shall bring this to the Buyer's attention. It shall be the responsibility of the Seller to obtain resolution and disposition of deviation with the Buyer and other appropriate parties and authorities.

4.3 The intent of this specification is to supplement the requirements of the codes specified herein and to encompass the means whereby the design objective is satisfied.

4.4 All standards and material specifications shall be per latest revision in effect on the date of the contract.

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5.0 DESIGN REQUIREMENTS

5.1 Operating Conditions

5.1.1 Internal Pressure

Design Pressure: 1250 psig at bottom of the reactor vessel
Normal Operating Pressure: 1000 psig at top of reactor vessel

5.1.2 Temperature

Design Temperature:	575°F
Normal Operating Temperature:	546°F

5.1.3 Reactor Core and Internal Weight

The weight of the reactor core and internal structure, centers of gravity and distribution of loadings are shown on Drawing 886D482.

5.1.4 Water Weight

The weight of water contained in the vessel for various conditions of operation are presented on Drawing 886D482.

5.1.5 Pipe Reactions

The Buyer shall provide the Seller with the pipe reactions which the connecting piping will apply to all nozzles with a nominal size larger than the reactor vessel wall thickness and those nozzles which in addition are subjected to significant thermal cycling. The reactions will be limited by the Buyer such that the combined stress as due to pipe reactions and design pressure in the vessel shell at the nozzle attachment will not exceed the design stress allowed by the ASME Code, Section III. These pipe reactions shall be used in the detailed stress analysis required by the Code and performed by the Seller. This analysis shall include the thin section of the nozzle in the vicinity of the weld preparation for connecting piping, any bi-metal weld and shall take into account the nozzle cladding.

5.1.6 Control Rod Drive Weight and Reaction

The momentary reactions which are suddenly applied to each control rod drive housing in the vessel bottom head are presented on Drawing 886D482.

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ATOMIC POWER EQUIPMENT DEPARTMENT

PURCHASE SPECIFICATION

SPEC. NO. 21A1112 REV. NO. 6
SH NO. 5 CONT ON SHEET 6

5.1.7 Steady State Thermal Conditions

Steady state metal temperatures will be computed by the Buyer for no more than twelve locations on the reactor vessel. The locations will include the head and shell closure flanges, the shell adjacent to the reactor core, the bottom head and major nozzles including the control rod drive nozzles. Temperature gradients through the shell wall adjacent to the portion of the reactor core peak flux zone will be computed by the Buyer and furnished to the Seller.

5.1.8 Cyclic Loading

The thermally induced stresses which result from the transients listed in Attachment D shall be computed for the components listed. The cyclic stress ranges which result from these and the following conditions shall be evaluated in a fatigue analysis according to the ASME Code Section III.

The additional conditions are:

a) Zero stress condition
b) Isothermal condition at 546°F and 1000 psi inside vessel.
c) Isothermal conditions at 70°F and 1000 psi inside vessel 120 cycles.
d) For the closure flanges and bolting - the cold bolt-up condition 120 cycles.

5.1.9 Earthquake Loads

Earthquake loads shall be taken into account in accordance with the criteria and load presented on Drawing 886D482.

5.2 Design Considerations

5.2.1 Design Objective

The objective shall be to design and fabricate this reactor vessel to have a useful life of forty years under operating conditions specified by the Buyer.

5.2.2 Reactor Vessel Supports

Reactor Vessel supports, internal supports, their attachments and adjacent shell shall be designed to take maximum combined loads including control rod drive reactions, earthquake loads, and jet reaction thrusts as defined on Drawing 886D482. There shall be no gross yielding of the reactor vessel supports causing permanent displacement under these conditions.

5.2.3 Stress Concentrations

Care shall be taken in design and fabrication to minimize stress concentrations at changes in sections or penetrations. Fillet radii shall be equal to at least half the thickness of the thinner of the two sections being joined. If reinforcement for openings (except the control rod drive and in-core flux monitor nozzles) requires local vessel shell added thickness, such reinforcement shall extend at least 1-1/2 times the diameter of the opening from the center of the opening. These requirements are not to be construed as a waiver for evaluating the stresses for use in the analysis for cyclic operation.

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5.2.4 Corrosion Allowance

Exterior exposed ferritic surfaces of pressure-containing parts including heads, shell, flanges and nozzles shall have a minimum corrosion allowance of 1/16 inch. The interior surface of carbon or low alloy steel parts exposed to the reactor coolant shall also have a minimum corrosion allowance of 1/16 inch. If the main closure head is left unclad, its interior surface shall also have a minimum corrosion allowance of 1/16 inch.

5.2.5 Main Closure Seal

The reactor pressure vessel main closure seal shall be a double seal designed to have no detectable leakage through the inner or outer member at all operating conditions. These conditions include, but are not limited to: (a) cold hydrostatic pressure test at the design pressure, (b) heating to design pressure and temperature at a rate of 100°F/hr., maximum, (c) operating for extended periods of several months duration at operating conditions, and (d) cooling at a rate of 100°F/hr., maximum.

5.2.6 Design Stress

Design stress values used in the calculations shall be as contained in ASME Section III and applicable interpretations of ASME Boiler and Pressure Vessel Code for materials covered therein. The design stress values for ASME, Section III calculations for other materials approved by the Buyer in accordance with Paragraph 8.1 of this specification shall be determined per Appendix II, ASME Code, Section III.

5.2.7 Dimensional Control

Seller shall show the method of controlling measuring and maintaining alignment and location of control rod drive penetrations with the vessel and core supports.

5.2.8 The reactor shall be designed to minimize retention pockets and crevices.

6.0 DESIGN ANALYSIS

6.1 Requirements

The Seller and the Buyer shall perform the design calculations and analyses as required by the applicable Standards and Codes indicated in Section 4.0. The requirements of Article 4, ASME Code, Section III, shall be fulfilled. The division of responsibility for the analyses shall be in accordance with paragraph 6.1.3. The analysis required shall be performed in two divisions as follows:

6.1.1 Stress Analysis

A stress analysis shall be performed in accordance with Section N-430, ASME Code Section III. Calculations shall be performed in accordance with paragraph N-431 to verify that the minimum wall thickness is provided. A detailed stress analysis shall be performed in accordance with paragraph N-432. This analysis shall take into account all combinations of loads in conjunction with metal temperatures, as indicated in Section 5.0 above, and Drawing 886D482 within the Design Stress Criteria of ASME Code Section III, Article 4.

6.1.2 Analysis for Cyclic Operation

An analysis shall be performed in accordance with Section N-415 of the ASME Code, Section III, to determine that the vessel is suitable for the cyclic loading conditions of paragraph 5.1.8 above. This analysis shall also be performed within the design stress criteria of Section III, Article 4, to establish whether the design objective in paragraph 5.2.1 above is reached. The analysis will be used to determine the adequacy of any required thermal baffling used to control or limit thermal stresses and to place safe operating limits on the cyclic conditions imposed on the vessel where it is reasonable to control them, as in the start-up heating rate and shut-down cooling rate.

6.1.3 Division of Responsibility

The Seller and the Buyer shall perform jointly the design analysis required by this specification.

6.1.3.1

The seller shall perform calculations to satisfy limits on primary general membrane stress (P_M), primary local membrane stress (P_L), primary bending (P_B), and secondary membrane plus bending stresses (except thermal stresses) (Q) from specified steady state conditions. Also included are calculations necessary to reinforce openings per Paragraph N-450, except the calculations necessary to satisfy the cyclic conditions and Paragraph N-451 (b) which are the responsibility of the Buyer.

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6.1.3.2

The Buyer shall perform the transient and steady state thermal analysis and the analysis for cyclic operation on all components requiring such analysis. These analyses will provide the stress categories Q and F of Paragraph N-414, ASME Section III. This type of analysis will cover but not necessarily be limited to the following parts of the reactor vessel:

a. Emergency cooling nozzles (safe end and thermal sleeve)

b. Feedwater nozzles (safe end and thermal sleeve)

c. Control rod drive hydraulic system return nozzle (safe end and thermal sleeve)

d. Vessel Support Skirt

e. Refueling bellows support skirt

f. Closure flanges

g. Bolting

h. Control rod drive penetration

6.1.3.3

The analyses which are the responsibility of the Buyer but are made with the Sellers assistance, shall be checked and signed by the Buyer.

6.1.3.4

The Seller shall fulfill the requirements of Paragraph 4.0 Codes, and produce the summary report required by Paragraph 6.8. The Buyer shall prepare its portions in suitable form for reproduction.

6.2 <u>Calculation of Stresses</u>

The detailed structural analysis required to meet the requirements of 6.1 shall be made for the stresses resulting from internal pressure, external and internal loadings, and the effects of steady and fluctuating temperatures and loads for regions given in 6.3 which involve changes of shape, structural discontinuities, and points of concentrated loadings.

Where dimensions and loading conditions permit, the adequacy of structural elements will be verified by comparison with completely analyzed elements. The calculations shall include a complete analysis of stresses under steady state and transient conditions to determine suitability of the design with respect to the allowable stress given in ASME Code, Section III, and to determine the operational limitations with respect to fatigue of the reactor vessel materials over the life of the reactor vessel (Design Objective) using the loading conditions supplied by the Buyer.

6.3 <u>Parts of the Reactor Vessel Assembly to be Analyzed</u>

The parts of the reactor vessel to be analyzed shall include: head closure, bottom head, shell adjacent to reactor core, reactor vessel supports and stabilizers, supports for reactor vessel internals, control rod drive penetration, feedwater nozzle, poison nozzle, emergency core cooling nozzles, drive system return nozzle, and all nozzles 10" or larger in size.

6.4 <u>Closure Head Seal Calculation</u>

To assure meeting sealing requirements of the main closure seal as specified in paragraph 5.2.5 above, the relative rotations of the flanges shall be calculated. These rotations shall be used to demonstrate analytically satisfactory seal performance using the following assumptions:

6.4.1 The mating surfaces of the flanges shall be assumed rigid.

6.4.2 The rotation shall be assumed to cause contact over the minimum area which will sustain the loading between the faces when stressed to the yield strength at the metal temperature.

6.4.3 The flange faces shall be assumed to diverge from the contact area, specified in paragraph 6.4.2, through the angle of calculated relative rotation less any radial taper machined on the face(s) to accommodate the flange rotations.

6.4.4 It may be assumed that the seal will be maintained if, at both O-ring seal locations, the separation between flanges is less than the minimum elastic spring-back of the O-ring.

6.5 <u>Calculations</u>

The calculations shall be clear and in sufficient detail to permit independent checking. Specific references shall be given for all formulas and methods used or the formulas and methods shall be derived independently. Calculation shall be submitted to the Buyer for approval.

6.6 Descriptions of Computer Programs

If computer programs are used to obtain solutions to design problems, the Seller shall furnish the Buyer the description of each different computer program used. These descriptions shall be furnished with the first issue of the design calculations incorporating such programs. The computer program description shall include computer type, program capabilities, assumptions, limitations and statement of availability.

6.7 Measurement Reports

Measured values of strain, deflections or stresses resulting from tests on models or actual reactor vessels shall be supplied to the Buyer by the Seller. These reports shall include all information necessary to duplicate the conditions required to obtain the results reported.

6.8 Summary Report

After completion of the reactor vessel design, the Seller shall furnish the Buyer additional copies of all calculations plus a summary report of results of all computations. Each copy shall be bound in a suitable paper binding and indexed.

7.0 CONSTRUCTION

The reactor vessel body including all components which contain pressure including the shell, lower and upper heads shall be made of rolled plate and/or forgings welded with full penetration welds throughout except as noted in 7.3.5. The shell and head flange and nozzles shall be forged.

7.1 Shell and Heads

7.1.1 Longitudinal and circumferential weld joints in the reactor vessel shall be oriented so as not to intersect openings or penetrations, wherever practical. Circumferential weld seams should avoid regions of highest neutron flux in the core region, if practical. The region of highest neutron flux occurs between the mid-plane and top of the core.

7.1.2 Bottom Head

The section of the bottom head which encompasses the penetrations for the control rod drives and in-core flux monitors shall be either a single forging or dished plate, if practical. If this is not practical and a weldment is used, the orientation of the weld sections shall as far as practical minimize the number of intersections of weld seams with penetrations.

7.1.3 Top Head

The top head shall be either a single forging or dished plate or shall be fabricated of sections welded together, with the orientation of the weld seams such that no seams intersect openings or penetrations.

7.1.4 Weld Joints

Weld joints shall be designed to facilitate a maximum of radiographic examination per the ASME Boiler and Pressure Vessel Code, Section III, paragraph N-624.

7.2 Head Closure

7.2.1 Assembly and Disassembly

7.2.1.1 The head closure shall be designed for removal and reassembly, using 4 or more hydraulic stud tensioners.

7.2.1.2 It shall be the design objective to replace and remove the head within 16 hours elapsed time. Specifically, the cycle shall include placing the head over the studs, tightening the studs to operating bolt-up loads, unbolting and removal of the head over the studs. It is expected that 120 such cycles will be performed during the life of the reactor vessel.

7.2.2 Seals

7.2.2.1 The head seal shall be a double seal with a vent between the seals through which leakage of the inner ring can be detected. The seal vent shall be designed for full design pressure of the reactor vessel.

7.2.2.2 The seal shall be metal O-ring type with pressure equalizing vents on I.D.

7.2.2.3 The grooves for the O-rings shall be placed in the reactor head flange. Suitable fasteners shall be provided to hold the O-rings in the grooves during head removal and assembly operations.

7.2.2.4 Provisions shall be made for installation of a low pressure leak detection system outside of the second seal, and may be outside of the bolt circle. The provisions shall include a vent through the vessel flange with extended 1" nipple and socket weld fitting and either a shallow groove or other suitable backing to retain a soft asbestos braided packing. There shall be no protruding parts of this low pressure seal beyond the O.D. of the head and vessel flange.

7.2.3 Bolting

7.2.3.1 Studs shall be used to secure the reactor vessel head. Stud, nut and bushing threads shall be in accordance with Drawing 885D911.

7.2.3.2 The stud bolt holes in the reactor vessel flange shall be bushed with removable bushings. Keys shall be provided for each bushing to prevent rotation of the bushings when removing studs.

7.2.3.3 Spherical washers shall be used with the studs to minimize bending of the studs.

7.2.3.4 It shall be possible to remove and replace the head with the studs installed. To facilitate head removal and replacement, three special guide caps shall be provided to couple onto three studs. The lengths of the guiding surfaces of the guide caps shall be staggered so that the shorter of the three guide caps shall extend above the top of the installed studs for a minimum distance of 4 inches. The length of the three guide caps shall be staggered in 3-inch minimum increments. The internal threads of the guide caps shall be similar to the stud nuts threads. The upper end of the guide caps shall be provided with a conical lead-in taper and a horizontal through-hole bored to accommodate a round bar for wrenching.

7.2.3.5 Flange hole, bushing, and stud designs shall be such that the studs stand perpendicular to the flange surface when the studs and bushings are bottomed in the holes to facilitate removal and replacement of vessel head over studs as called for in Paragraph 7.2.3.4.

7.2.3.6 The surface of all threads in the studs, nuts and bushings shall be given a phosphate coating to act as a rust inhibitor and to assist in retaining lubricant on the surfaces. An approved lubricant should be applied to the stud threads as soon as possible after coating.

7.2.3.7 A stud sling for the main closure studs shall be provided. The stud sling shall include a swivel and counter-weight spring to support the weight of the stud during turning of stud into vessel flange. Studs are to be provided with a wrenching surface accessible when suspended on sling.

7.2.3.8 All main load-carrying threads and spherical washers shall be assembled only after cleaning, gaging, and lubricating. In no case during fabrication or testing shall these parts be assembled without lubricant. Only thread lubricant approved by the Buyer shall be used.

7.2.4 Flanges

7.2.4.1 The top head flange surface shall be machined or the area around each stud hole spot faced. Spot facings shall be complete and extend beyond washer O.D. to accommodate maximum eccentricity of stud in head flange bolt hole. The top head flange surface, with or without spot facings, must accommodate and provide proper bearing area for the stud tensioner feet.

7.3 Nozzle Ends

7.3.1 The ends of all nozzles other than flanged nozzles shall be prepared for welding in accordance with Drawing 107C5305. Nozzle safe ends are considered to be part of the vessel, not part of the connecting piping but in no case shall the safe end wall thickness be less than the wall thickness of the connecting pipe.

7.3.2 Where thermal sleeve nozzles are specified to a nominal size, the size of the pipe through the nozzle as well as the nozzle external end shall be the nominal size specified for the nozzle. Thermal sleeves shall be supplied by the Seller.

7.3.3 The Buyer will furnish information on the wall thickness, t_p, of all piping connections and will set the inner bore diameter including tolerances and allowances of the connecting piping will follow ASA Standards. The Buyer will use the formulas and allowable stresses of B31.1 for establishing the required piping wall thicknesses. Nozzle safe end wall thickness shall be governed by Drawing 107C5305 and will in general be greater than required by Section III.

7.3.4 Details of the transition weld preparation shall be submitted to the Buyer for approval.

7.3.5 Nozzles of 3" nominal size or larger shall be full penetration welded to the vessel. Nozzles less than 3" nominal size may be partial penetration welded if permitted by ASME Code, Section III.

7.4 The vessel top head nozzles shall be provided with 1500 pound weld neck flanges with small groove facing. Mating 1500 pound flanges with small tongue facing, gaskets and a complete set of studs and nuts shall also be provided. The loose flanges for the 6 inch instrument nozzles shall be blind, the remainder shall be weld neck. The flanges and gaskets shall be in accordance with ASA Standards B16.5. The threads on studs and nuts shall be 8-pitch series in accordance with ASA Standard B1.1.

7.5 Reactor Vessel Supports

7.5.1 External and internal supports shall be provided as an integral part of the reactor vessel. The location and design of the supports shall be such that stresses in the reactor vessel and supports will be within ASME Code limits due to reactions at these supports. The design pressure differential across the core shroud support shall be 100 psi (higher pressure under the support) occurring at the vessel design temperature. The design of the core shroud support shall also take into account the restraining effect of the components attached to the support and the weight and earthquake loading as shown on Drawing 886D482.

7.5.3 The drain nozzle shall extend 12 to 16" below the bottom of the reactor vessel and shall be of the full penetration design.

7.6 External Attachments

7.6.1 Brackets to support insulation shall be provided on the exterior of the reactor vessel in accordance with Drawing 886D482

7.6.2 Provisions shall be made for the attachment of thermocouples in mounts on the reactor vessel exterior as specified on Drawing 886D482.

8.0 MATERIALS

8.1 All materials to be used shall be indicated on the Seller's drawings. The Seller shall submit for the Buyer's approval, all material selections and material purchasing specifications.

8.2 Records

The Seller shall maintain complete records showing use of all materials so that it will be possible to relate every component of the finished reactor vessel to the original certification of the material and the fabrication history of the component. The Seller shall prepare a summary of the heat number, chemical composition and mechanical properties for each reactor vessel component.

8.3 Forgings

Low alloy steel forgings for pressure parts shall be made in accordance with ASTM A508 in accordance with ASME Code Case 1332-3, Paragraph 5. Nozzles which are partial penetration welded as specified in 7.3.5 may be nickel-chromium-iron forgings made in accordance with ASME SB-166 modified in accordance with Code Case 1336. The molten steel shall be vacuum treated prior to, or during, the pouring of the ingot in order to remove objectionable gases, particularly hydrogen.

8.4 Plate

Plate for pressure parts shall be in accordance with ASTM A533, Class I Grade B, Firebox Quality, in accordance with ASME Code Case 1339-2. Plate ingots shall be produced by vacuum degassed pouring.

8.5 Castings

The use of castings will be considered by the Buyer but specific Buyer approval shall be required. Castings for pressure parts shall be made in accordance with ASME SA-356, Grade 10, Code Case 1333, Paragraph 1.

8.6 Material for pressure parts shall be selected and worked to produce as fine a grain size as practical. It shall be an objective of the fabrication technique to retain a grain size of 5 or finer in all material. Grain size shall be determined by the method in ASME E112.

8.7 Heat Treatment

Heat treatment of carbon and low alloy steel pressure parts shall consist of normalizing and then tempering at not less than 1200°F. For section thickness over 3 inches nominal, heat treatment shall consist of accelerated cooling from the austenitizing temperature to below the martensite finish temperature followed by tempering at not less than 1200°F to obtain tensile and impact properties comparable to those developed by normalizing and tempering section thickness of less than 3 in. nominal.

8.8 Mechanical Properties

The low alloy steel forgings, plate and castings for pressure parts shall be tested in accordance with Paragraph 10.3 and shall have the mechanical properties required therein in addition to those required by the applicable ASME Specification.

8.9 Studs, Nuts, Bushings, and Washers for Main Vessel Closure

8.9.1 Studs shall conform to ASTM A540, Grades B23 or B24 and ASME Code Case 1335-2, Paragraph 4, Class 3, 4 or 5.

8.9.2 Nuts, bushings and washers shall conform to ASTM A540, Grades B23 or B24, and Code Case 1335-2, Paragraph 4, Class 3, 4, or 5 but to suit the stud material used. It shall be the objective to have a minimum difference in hardness of 5 Rockwell C points from the stud material.

8.9.3 Hardness and impact properties shall meet the requirements of paragraph 10.3.2.5.

8.10 Cladding Material

All internal carbon and low alloy steel surfaces of the reactor vessel including the closure head and closure head flange mating surfaces, shell flange and mating surface, shell, bottom head, nozzles for connecting stainless steel piping, and internal attachments shall be clad with weld overlay meeting the following requirements:

8.10.1 Weld overlay cladding shall be a minimum of 0.125 inches total thickness. The finished surface shall have a composition equivalent to ASTM A371, Type ER308 or A240 Type 304 except the carbon content shall not exceed 0.08%.

8.10.2 Cladding in the "as-clad" condition is acceptable, provided the resulting surface finish does not interfere with the ultrasonic and liquid penetrant test requirements.

8.10.3 The sealing surfaces of the reactor vessel head and shell flanges shall be weld overlay clad with austenitic stainless steel which consists of a minimum of two layers and a minimum of 0.25 inch total thickness. The first layer shall be deposited with an analysis equivalent to ASTM A371, Type ER309. The second and sub-sequent layers shall have a composition equivalent to ASTM A371, Type ER308, except the carbon content shall not exceed 0.08%. Minimum thickness of 1/4 inch shall apply after all machining, including area under groove.

8.11 Attachments

8.11.1 Internal attachments other than the weld clad ferritic attachments shall be annealed stainless steel, Type 304 per ASTM A240 or ASTM A276, or Type F304 per ASTM A182. The core support structure shall be stainless steel clad low alloy or carbon steel, solid nickel-chromium-iron alloy per ASME SB166, 167, or 168, or annealed stainless steel, Type 304 per ASTM A240 or ASTM A276, or Type F304 per ASTM A182.

8.11.2 External attachments to the reactor vessel shall be of the same material as the reactor vessel base material, or shall be of a material which has mechanical and impact properties compatible with the base material. Where welds must be made to the attachments in the field, the material selected shall not require pre-heat or post-weld heat treatment.

8.12 Nozzle Safe Ends and Flanges

8.12.1 Nozzle ends for austenitic pipe shall be ASTM A336, Class F8 or F8m; A240, Type 304, or Type 316; or A376, Type 304 or Type 316 solution heat treated stainless steel, depending upon the mating pipe material selected by the Buyer. Nozzle ends for carbon steel pipe shall be ASTM A105, Grade II, forgings except phosphorous content shall be 0.035% Max. and sulphur 0.040% Max; ASTM A508 Class I; or ASTM A516 Grade 70. Proportions shall be as shown on Drawing 107C5305.

8.12.2 Standard flanges for flanged nozzles and separate mating flanges shall be ASTM A182, Grade F304, stainless steel.

8.12.3 Studs for standard flanges shall be SA193, Grade B7. Nuts for standard flanges shall be SA194, Grade 2H.

8.13 Pipes and tubes shall be ASTM A213, A249, A312, A376, solution heat treated, Grade TP304 or TP316; or A240, Type 304 plate welded and radiographed in accordance with ASME Code, Section III, Paragraph N624.

8.14 Miscellaneous bolting material shall be subject to the Buyer's approval.

8.15 Weld Electrodes and Rods

8.15.1 Material for weld electrodes and rods shall be selected from ASTM A233, A298, A316, A371 or equivalent for other processes and reported to the Buyer for approval.

8.15.2 All austenitic stainless steel welds and weld cladding shall contain controlled amounts of ferrite, confirmed by quantitative tests. The procedures for control of, and testing for the ferrite content of welds and weld cladding shall be submitted to the Buyer for approval. The acceptance standard for quantitative tests shall be either % Cr = 1.9 x % Ni, or 5% ferrite minimum.

8.16 Alternate Materials

The Seller shall be free to suggest alternate materials during preparation of detailed drawings and shall bring such alternates to the attention of the Buyer, but shall not make substitutions without approval of the Buyer. Request shall include:

8.16.1 Reason for substitution.

8.16.2 Identification of the component or parts involved.

8.16.3 Either the complete material specification similar to ASTM for each type and form of proposed material, or the information as follows:

a) Type of Service (Structural, High/Low Pressure, Temperature, Weldable)
b) Manufactured Form (Pipe, Plate, Tube, Bar, Bolting)
c) Size, Thickness Limits
d) Alloy Grades (C-Steel, Alloy Steel, Stainless Steel Designations)
e) Steel-Making Process (Open Hearth, Basic Electric)
f) Forming Process (Hot Forged, Hot/Cold Rolled, Drawn, Seamless Welded, Cast)
g) Heat Treatment, Stress Relief Parameters
h) Type, Location and Number of Mechanical Tests (Tensile, Bend Homogeniety, Hydrostatic)
i) Mechanical Property Acceptance Limits
j) Chemical Composition Acceptance Limits
k) Inspection Requirements such as: Radiography, Liquid Penetrant, Magnetic particle, Ultrasonic Including Acceptance Limits.
l) Surface Finish Acceptance Limits

8.16.4 Allowable Stresses (If not an ASME Material)

8.16.5 For major pressure parts, additional information will be required regarding details of previous applications of the material, impact strength, NDT temperature, micro-structure variations, creep, stress rupture, hardness, radiation damage, welding, forming, corrosion and temperature effects as applicable for engineering evaluation of the application and as required for code purposes.

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9.0 FABRICATION

9.1 Procedures

9.1.1 The Seller shall submit for the Buyer's approval, all of the following procedures and procedure specifications:

9.1.1.1 Heat treatment procedures for all thermal processes exceeding 800°F after the mill rolling or forging or foundry casting operation.

9.1.1.2 Forming and bending procedures for all forming during fabrication subsequent to mill forging or rolling or foundry forming and cladding.

9.1.1.3 Welding and weld repair procedures including temporary welds as required in accordance with the ASME Code, Section IX, Paragraphs Q-10 and 11, and QN-10 and 11, Section III, Paragraph N-540.

9.1.1.4 Method of qualifying welding procedures and performance, if other than ASME Code, Section IX and III.

9.1.1.5 Repair procedures for major and minor defects as defined in Paragraph 9.4.

9.1.1.6 Drawings showing location and preparation of test specimens, including specimens required in Attachment B.

9.1.1.7 Fabrication schedule including the detailed sequence to be followed in fabrication of the vessel.

9.1.1.8 All cleaning procedures, preserving procedures and a list of cleaning agents and preservatives together with their chemical content which shall be used during fabrication and in preparation for shipment. In lieu of a complete chemical analysis, the Buyer shall accept a report which states the chlorides, fluorides and sulfur content. Other harmful elements should also be reported.

9.1.2 All work by the Seller or his sub-suppliers shall be performed in accordance with Buyer approved drawing, and fabrication and test procedures.

9.2 Material Cutting

9.2.1 Stainless steel and carbon steel shall be cut to size or shaped by machining, shearing or thermal cutting.

9.2.2 Thermal cutting of stainless steel shall be followed by the removal of approximately 1/32" depth from the cut surface. Thermal cutting of carbon steel shall be followed by the removal of oxides.

9.3 <u>Welding</u>

9.3.1 The reactor vessel base material pre-heat and interpass temperature shall be as specified in the welding procedures, but in no case less than 300°F, except weld overlay pre-heat which shall be no less than 200°F. Pre-heat temperature shall be maintained after welding until start of post-weld heat treatment. Pre-heating techniques shall be such as to ensure that the full thickness of the weld joint preparation and adjacent base material is at the specified temperature for the distance of "T" or two inches, whichever is greater, where "T" is the material thickness.

9.3.2 When stainless steel or nickel-chromium-iron alloy is welded to itself or to each other, no pre-heat is required, except when the heat-affected zone reaches ferritic base material as in the cases of welding to buttered nozzle ends or cladding. When the buttering or cladding is less than 1/4 inch thick, pre-heat to at least 200°F is required, followed by post-weld heat treatment except that subsequent welding to cladding greater than 1/8 inch thick may be done without preheat if the specific welding procedure is qualified to show that the heat affected zone does not reach the base metal.

9.3.3 All surfaces (to be welded) shall be free of cavities or protrusions which may interfere with the welding procedure.

9.3.4 Pre-heat, welding and post-weld treatment shall be planned and conducted to minimize undue distortion or warping of the parts and preclude cracking.

9.3.5 Machined surfaces and threads shall be protected against weld splatter.

9.3.6 Stainless steel welds shall be cleaned with stainless steel wool or stainless steel brushes before adding the next bead and following the final bead to facilitate inspection. The light oxide discoloration which forms on the weld surface need not be removed.

9.3.7 Welds shall be cleaned of slag and flux between passes and following the final deposit.

9.3.8 Any cracks, blow holes, or other defects which appear on the surface of weld beads shall be removed by machining, chipping, grinding, or arc gouging. Austenitic weld repairs, if arc gouged shall be followed by grinding. Austenitic welds shall not be peened; ferritic welds may be peened under controlled conditions after approval by the Buyer.

9.3.9 Wide welds to overcome poor fit are not permissible. Poor fits shall be remedied by suitable means such as regrooving, and approved by the Buyer. Except for small cavities, the Seller shall not correct a plate edge deficiency unless approved by the Buyer. The Buyer may require radiography or other methods of examination of welds used to correct plate edge deficiencies.

9.3.10 Post-weld heat treatment temperature shall be 1150°F +25°F -50°F. Interstage post-weld heat treatment holding time shall be 15 minutes minimum. Final post-weld heat treatment holding time shall be one hour per inch of thickness, minimum.

9.4 Repair of Defects

Repair procedures shall be prepared for the repair of all defects. Major defects shall require prior approval by the Buyer and may require witnessing by the Buyer's representative. Major repair is defined as (1) a repair to material other than weld metal which requires an excavation greater than 3/8 inch deep or 10 percent of the wall thickness, whichever is less; (2) the repair of any cracks, other than crater cracks, in any material or weld metal; and (3) the repair of any defect which is indicative of either a fundamental material problem or a process out of control. A minor repair is defined as all other repairs.

9.5 Cleaning

9.5.1 Interior Surfaces

After the Seller has completed all other work, the interior surfaces of the reactor vessel shall be thoroughly cleaned to be visibly free of lubricants, weld splatter, chips, embedded iron particles and other foreign materials. A preferred method for cleaning and rinsing is use of high pressure water blasting equipment for these operations given in Paragraph 10.8. To maintain cleanliness of the interior of the vessel and head during drying and sealing, the personnel required to enter the vessel or head should wear clean cloth shoe covers and clean clothes. The vessel shall be sealed to prevent entry of dirt or foreign materials. Seals used on nozzle ends and flange faces shall not alter weld preparations or sealing surfaces.

9.5.2 Exterior Surfaces

Exterior carbon steel surfaces shall be cleaned of oil and grease after which mill scale, rust scale, and other foreign matter shall be thoroughly removed by such means as sandblasting as specified by the Buyer. All surfaces shall be brushed or air cleaned to remove all traces of sand or grit.

10.0 INSPECTION AND TEST

10.1 General

The Seller shall submit for the Buyer's approval, the following inspection and test procedures:

10.1.1 Ultrasonic Examination Procedure for the following:

10.1.1.1
1. Forgings
2. Plate
3. Welds
4. Weld build-ups
5. Cladding
6. Tubular Products

10.1.2 Magnetic Particle Examination Procedures for the Following:

10.1.2.1 Carbon steel & low alloy steel forgings

10.1.2.2 Carbon steel & low alloy steel welds

10.1.2.3 Weld build-ups

10.1.2.4 Bolting

10.1.2.5 Carbon steel and low alloy steel tubular products

10.1.2.6 Carbon steel and low alloy steel castings

10.1.2.7 Edge preparations of carbon steel and low alloy steel materials.

10.1.3 Liquid Penetrant Examination Procedures for the Following:

10.1.3.1 Austenitic Forgings

10.1.3.2 Austenitic welds

10.1.3.3 Austenitic weld buildup

10.1.3.4 Cladding

10.1.3.5 Austenitic tubular products

10.1.3.6 Austenitic castings

10.1.3.7 Edge preparations of austenitic materials

10.1.4 Radiographic examination procedures for welds, castings, for each type of radiographic source above and below 2 Mev.

10.1.5 Hydrostatic Examination Procedures

10.1.6 Leak Check Procedures

10.1.7 Methods, processes and equipment to be used in establishing "as-built" dimensions and alignment checks which are not generally used in a typical industrial shop.

10.2 Definitions

10.2.1 "As-Fabricated" Specimens

"As-fabricated" specimens are mechanical test specimens taken from carbon and low alloy steel forgings and plates used in the vessel fabrication from each heat and heat treatment lot and from welds between base material made by each welding procedure used and in a thickness equal to or greater than the thickest weld made with each procedure. Coupons for "as-fabricated" specimens shall be taken from the forgings or plates following all hot working or forming and all heat treatment except post-weld heat treatment. These coupons shall then be subjected to a post-weld heat treatment equivalent to the treatments which the parts it represents will receive in the completed vessel. This shall consist of holding the coupon at the post-weld heat treatment temperature for a time equal to or greater than the longest accumulated time any part it represents shall be at the post-weld heat treatment temperature.

10.2.2 "1/4T x T" Location

The "1/4T x T" location of specimens is defined as a location within the material no closer than "1/4T" from one quenched surface, and no closer than "T" from any other quenched edge, where "T" is the nominal thickness of the material.

10.2.3 NIL-Ductility Transition (NDT) Temperature

The nil-ductility transition (NDT) temperature is defined as the temperature at which a specimen is broken in a series of tests in which duplicate no-break performance occurs at a temperature 10°F higher, when tested in accordance with ASTM E208.

10.2.4 Impact-Transition Curve

A curve representing breaking energy vs. temperature from at least twelve Type A Charpy-V specimens, tested in accordance with ASTM A370, except each specimen tested at a different temperature. The temperature range of testing shall establish the upper plateau, the transition region, and the lower plateau. Each plateau shall be determined by at least one, but not more than two points. The remain ng specimens shall be used to develop the transition region. The lower plateau need not be developed if it occurs below -80°F.

10.2.5 A "lot of material" consists of all material from one heat (one melt) in a heat treatment furnace.

10.3 Material Mechanical Tests

10.3.1 Mechanical Properties

10.3.1.1 Impact properties of all carbon and low alloy steel used in the main closure flanges and the shell and head materials connecting to these flanges shall meet the requirements of the ASME Code, Section III, Paragraph N-330 at a temperature no higher than 10°F. In addition, this material shall have an NDT temperature no higher than 10°F as determined per ASTM E208.

10.3.1.2 Impact properties of all other "as-fabricated" carbon and low alloy steel pressure containing material and the vessel support skirt material shall meet the requirements of the ASME Code, Section III, N-330 at a temperature no higher than 40°F. In addition, this material shall have an NDT temperature no higher than 40°F as determined per ASTM E208. The actual NDT temperature of all material opposite the center of the active fuel of the core as indicated on Drawing 886D482 shall be determined.

10.3.1.3 Tensile test properties of all materials shall be inspected and tested to meet the requirement of the applicable ASME Code or ASTM specification.

10.3.1.4 Test data shall be reported to the Buyer.

10.3.2 Required Number and Specimen Location

The number and location of tensile and impact test specimens required shall be per ASME Code, Section III, N-313.2 and the following depending on the form of the material. The following tests may be integrated with the tests required by the ASME Code and ASTM Specification wherever possible.

10.3.2.1 Vessel Flange and Head Flange Forgings

Tangential specimens, as-fabricated, shall be taken from locations per ASME Code, Section III, N-313.2 (d) (2). A total of at least 2 tensile, 6 Charpy-V impact and 4 drop weight specimens shall be tested for each flange from which 1 tensile, 3 Charpy-V impact and 4 drop weight specimens shall be located approximately 180° from the other specimens. The material shall meet the requirements of Paragraph 10.3.1.

10.3.2.2 Low-Alloy Steel Nozzle Forgings

Specimens, as fabricated, shall be taken from locations per ASME Code, Section III, N-313.2 (d) for forged nozzles. At least 2 tensile, 3 Charpy-V and 2 drop weight specimens shall be tested for each heat and heat treatment charge, except that nozzles with wall thickness of less than 4 inches and outside diameter less than 12 inches shall not require drop weight testing. The material shall meet the requirements of Paragraph 10.3.1.

10.3.2.3 In addition to the tests required by the ASME Boiler and Pressure Vessel Code, longitudinal specimens (parallel to the primary rolling direction), as-fabricated, shall be taken from the 1/4T x T location. At least 2 drop weight specimens shall be tested from the top end (top as determined by ingot pouring) or each mill rolled plate and each heat treatment charge. The material shall meet the requirements of Paragraph 10.3.1. Additional drop weight specimens shall be required for NDT temperature determination per Paragraph 10.3.1.2 for plates located opposite the center of the core.

10.3.2.4 Castings

Tangential specimens, as-fabricated, shall be taken from locations per ASME Code, Section III, N-313.2 (d). Castings 1000 lb. weight and under shall have a total of 1 tensile specimen, 1 metallographic specimen, and 3 Charpy-V and 2 drop weight specimens, tested for each heat and heat treatment charge. Castings over 1000 lb. weight shall have a total of 2 tensile specimens, 2 metallographic specimens, 6 Charpy-V and 4 drop weight specimens tested from which 1 tensile specimen, 1 metallographic specimen, 3 Charpy-V and 2 drop weight specimens shall be taken 180° apart and/or diagonally opposite. The metallographic specimens shall be for reference only. Additional drop weight specimens shall be required for NDT temperature determination in accordance with paragraph 10.3.1.2 if the casting is located in the core area. The material shall meet the requirements of paragraph 10.3.1.

10.3.2.5 Studs, Nuts, Bushings and Washers for Main Vessel Closure

Hardness tests shall be made on all main vessel closure bolting to demonstrate that heat treatment has been performed. Studs, nuts and bushings shall be hardness tested individually. One sample from each lot of washers shall be hardness tested. Impact tests required by ASME Code, Section III, paragraph N-330 shall meet the Code requirements at a temperature no higher than 10°F. In addition to the magnetic particle or liquid penetrant acceptance standards specified in ASME Code, Section III, paragraph N-325, axial defects of less than thread depth shall be investigated to determine their nature. Any cracks or sharply defined linear indications are unacceptable.

10.4 Welded Base Material - Mechanical Tests

10.4.1 ASME Code Weld Test Plates

The Seller shall prepare and test weld coupons of Category A and B joints in accordance with ASME Code, Section III, N-713. The impact test temperatures shall be determined in accordance with paragraph 10.3.1 of this specification. In addition to the tests required by the Code, 6 drop weight specimens shall be taken from the 1/4T x T location from these plates and, if different welding procedures are used, from plates for base material to base material welds of Category D joints as defined in ASME Code, Section III, N-461. Two each of the drop weight specimens shall represent the the base metal, heat affected zone and weld metal. The specimens shall meet the requirements of paragraph 10.3.1.2. Additional drop weight specimens shall be required in accordance with paragraph 10.3.1.2 if the welding procedure is to be applied in the area opposite the core.

10.4.2 One of the test plates of Category A or B required in 10.4.1 above shall be selected by the Buyer for the fabrication tests required in Attachment B, Paragraph 2. The Seller shall perform all required tests and reports. These tests are for information only, but time is of the essence and the tests should be performed and results reported as early as practical.

10.4.3 The Seller shall prepare and ship, but not test, Surveillance Test Program material and specimens in accordance with Attachment B, Paragraph 3.

10.4.4 Flange Forging Weld Test Plate

In the event the vessel and head flanges are made by welding two or more forged segments, the Seller shall prepare a weld test plate from the forging material. Impact and tensile specimens shall be prepared and tested. The specimens shall be prepared from material in the weld-heat-affected zone and from the weld metal. Test results shall meet the requirements of paragraph 10.3.1.

10.5 Ultrasonic Inspection

10.5.1 Ultrasonic inspection of plate and forged material shall be performed in accordance with ASME Code, Section III, except that ASME Case Interpretation 1338-2, Alternate 2 shall not be acceptable, and the plate material testing shall be a 100 percent volumetric inspection and shall be performed after forming and heat treatment. The following acceptance criteria shall apply in addition to Code requirements. A defect which causes any echo indication that exceeds 50 per cent of the indication from the calibration standard and that is continuous during movement of the transducer more than 3 inches in any direction shall be unacceptable. A chart shall be maintained of defects with 50 per cent or greater loss of back reflection.

10.5.2 Prior to connecting any attachment, support or bracket, except insulation and thermocouple brackets, to the interior or exterior of plate portions of the vessel by means other than groove welds below the plate, the plate shall be ultrasonically inspected. The plate shall be inspected to a depth at least equal to the thickness of the part being joined, and over the entire area of the subsequent connection plus a band all around this area of width equal to half the thickness of the part being joined. The inspection shall be in accordance with ASME Code, Section III, Paragraph N-321, using longitudinal wave technique. The surface shall be 100 per cent inspected with the transverse interval being no greater than 90 per cent of the crystal diameter.

10.5.2.1 Reference Standard

The Seller shall prepare a reference standard which consists of a flat bottom hole having a diameter equal to one-quarter of the thickness of the part being joined or 1/4 inch diameter whichever is greater. The bottom of the hole shall be one thickness of the part being joined below the plate surface. This reference standard shall be used for calibration purposes.

10.5.2.2 Acceptance Standards

Any defect which produces a trace line pattern equal to or in excess of the appropriate reference standard shall be unacceptable.

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10.5.3 The main closure stud, nut, bushing and washer material shall be ultrasonically tested following heat treatment and rough machining to 125 rms or better finish using both longitudinal and shear wave techniques. Longitudinal wave examination shall be performed on 100% of the cylindrical surface, and in addition on stud material from both ends of each stud. The longitudinal wave transducer shall have a maximum diameter of 1/2 inch. Shear wave examination shall be performed on 100% of the outer cylindrical surface in both axial and circumferential directions.

10.5.3.1 Reference Standards

The Seller shall prepare a reference standard of the same material, thickness and curvature as the part being examined. The reference standard shall contain calibration features as follows:

1) Longitudinal Wave-Radial Scan: 1/2 inch diameter flat-bottom hole having a depth equal to 10% of the material thickness.

2) Longitudinal Wave-End Scan: Flat-bottom hole with area equal to 1% of stud cross-section or 1/4 inch diameter, whichever is smaller, having a depth of 1/2 inch.

3) Shear Wave: Square bottomed notches 1 inch long and 3% of the part thickness in depth, both axial and circumferential.

10.5.3.2 Acceptance Standards

Any defect which produces a trace line pattern (echo indication) greater than the indication from the applicable calibration feature shall be unacceptable. A distance-amplitude curve may be used for the longitudinal wave examination. The curve may be a line established by plugging the hole and examining it from both sides of the material. For end examination of studs the curve may be established for half the stud length and applied to an examination from each end to the center.

10.6 Claddin.

10.6.1 Ultrasonic Inspection - Cladding General

10.6.1.1 The cladding bond shall be tested with the transducer on the clad side using a suitable couplant. The entire clad surface shall be inspected at intervals 1.4 times the base material thickness, but not greater than 12 inches, transverse to the direction of welding.

10.6.1.2 Reference Standard

The Seller shall prepare a reference standard which consists of a flat bottom groove in typical clad plate. The groove shall be 0.35 inch maximum width by at least one crystal diameter long, parallel to the direction of welding. The groove shall be formed by machining the base metal within 1/32" of the cladding interface and etched with nitric acid to remove excess ferritic material from the interface. This reference standard shall be used for calibration purposes.

10.6.1.3 Acceptance Standards

Cladding which produces a trace line pattern equal to or in excess of the appropriate Reference Standard shall be unacceptable if a continuous pattern occurs during movement of the transducer more than three inches in any direction or if one or more patterns occur during movement of the transducer less than one inch in any direction from the boundary of any one pattern.

10.6.2 Liquid Penetrant Inspection - Cladding General

10.6.2.1 All clad areas and clad repairs shall be liquid penetrant inspected per ASME Code, Section III, N-627. The following indications shall constitute unacceptable defects and shall be repaired.

10.6.2.2 Any crack-like indications or incomplete fusion.

10.6.2.3 Linearly-disposed spot indications of 4 or more spots spaced 1/4 inch or less from edge to edge of the indication.

10.6.2.4 Spot indications which are indicative of defects greater than 1/32 inch deep as revealed by bleed-out.

10.6.3 Ultrasonic Inspection - Cladding Special Areas

10.6.3.1 The flange seal surfaces shall be inspected for bond to the flanges as per 10.6.1 except that the inspection shall be over 100 per cent of the area. Prior to final machining the volume 1/8 inch above and below the surfaces on which the double seals will seat shall be 100 percent inspected for defect using longitudinal wave technique. The acceptance criteria shall be that any defect which produces a trace line pattern equal to or in excess of a 1/16 inch flat bottom hole may be unacceptable.

10.6.3.2 The final machined surfaces on which the double seals seat shall be inspected by surface wave technique. Any defect producing a signal greater than the signal produced by the 0.002 inch deep by 1/8 inch long spark machined groove in a reference standard which the Seller shall furnish may be cause for rejection.

10.6.4 Liquid Penetrant Inspection - Cladding Special Areas

10.6.4.1 The area of the flange seal surfaces on which the double seals seat shall be liquid penetrant inspected per ASME Code, Section III, N-627, except that any indication of any type shall be unacceptable.

10.6.5 Magnetic Particle Inspection - Plate Material

10.6.5.1 Both internal and external surfaces of all low alloy steel plate material shall be magnetic particle inspected per ASME Code, Section III, Paragraph N-626 following forming and heat treatment. The acceptance standard of ASME Code, Section III, Paragraph N-625.5 shall apply.

10.6.6 Openings in Pressure Parts

10.6.6.1 The entire surface of all openings for partial penetration nozzles, regardless of size, except for the seal leak detection connection, shall be examined in accordance with ASME Code, Section III, N-513.

10.6.6.2 The entire surface of the finished stud holes in the head flange and the holes in the vessel flange prior to tapping shall be examined by the methods of ASME Code, Section III, N-513. Any indication of cracks or linear indications shall be reported to the Buyer for information. Any crack or linear indication may be subject to removal and repair if required.

10.7 Welds

10.7.1 Radiographs

10.7.1.1 Gamma rays shall not be used unless approved by the Buyer.

10.7.1.2 Films shall be suitably marked to identify the weld. Film identification markings shall coincide with the detail drawing markings for each weld.

10.8 Hydrostatic Tests

10.8.1 Code Test

Immediately prior to hydrostatic testing, all interior surfaces of the vessel and head that will contact water during hydrostatic testing shall be thoroughly cleaned. Cleaning and degreasing shall be by the use of high pressure (greater than 5000 psi) deionized water containing 500 ppm by weight of TSP for water blasting all internal surfaces. These surfaces shall be subsequently water blasted with deionized water (no additives). The vessel shall be filled with deionized water for hydrostatic testing. The method of heating the vessel is subject to approval by the Seller.

Definitions: Deionized water

Conductivity	2 micro-mho/cm
Solids	10 ppm max
Chlorides	1 ppm max
Fluorides	1 ppm max
Sulfides	1 ppm max

TSP - Reagent grade per American Chemical Society Specification for tri-sodium-phosphate

CAUTION: Special care shall be taken to thoroughly water blast rinse with deionized water crevice areas such as between the bottom head and stub tubes and behind welded-in thermal sleeves directly following cleaning with TSP solutions until effluent conductivity is less than 5 micro-mho/cm.

After completion of fabrication but prior to shipment, while the vessel is supported on its normal supports, the reactor vessel shall be pressure-tested in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Paragraph N-714. Reactor vessel material temperature shall be at least 100°F. In no case, however, shall the water temperature be higher than 200°F. Suitable gasket material instead of metal "O" rings may be used for this test.

10.8.2 Second Hydrostatic Test

Following the Code test, the vessel shall be hydrostatically tested at design pressure with new metal "O" rings. This test shall demonstrate that the head seal meets the sealing requirements. Relative displacement and rotation of the head closure flanges during this test shall be measured in at least four places and reported to the Buyer. The measurements shall be made prior to stud tightening and at 250 psi intervals from zero psi to the design pressure.

10.9 The placing of the head, tightening the studs to operating bolt-up loads, unbolting and removal of the head over the studs shall be demonstrated. The elapsed times for each step shall be recorded.

10.10 Final inspection after hydrostatic test per ASME Code, Section III, N-618 shall include seal surfaces and the nozzle weld preparation.

11.0 SHIPMENT

11.1 Small Parts

Small, loose pieces, including bolting, tools, gaskets, etc., shall be adequately crated or boxed for protection during shipment. Parts subject to rusting shall be suitably protected. All pieces shall be marked with the equipment piece number or mark specified by the Buyer.

11.2 Shipping Weights and Dimensions

Estimated shipping weights and overall clearance dimensions of all major pieces to be shipped to the erection site shall be shown on the drawings when submitted to the Buyer for approval.

11.3 Shipping Skids

Shipping skids for components shall be designed to support the components adequately and securely during shipment to the erection site and to account for the means of movement lifting, and positioning to be provided by the Seller at the erection site.

12.0 SUBMITTALS

12.1 Tabulation (For Information Only)

Fabrication, qualification and inspection procedures, reports processes, and calculations are tabulated below (all of which require submittal to the Buyer in quantities as shown on Attachment A). This tabulation shall in no way be construed as being complete or limiting the documents necessary to meet the requirements of this specification.

Heat treatment procedure
Forming and bending procedure
Welding and weld repair procedure specification
Repair procedures
Cleaning and preserving procedures
Ferrite content or Ni/Cr ratio control procedure
Ultrasonic examination procedure
Magnetic particle examination procedure
Liquid penetrant examination procedure
Radiographic examination procedure
Hydrostatic examination procedure
Leak Check Procedure
Measurement reports
Summary reports
"As-built" dimensions and alignment checks procedures.

12.1 (Continued)

Design analysis calculations
Material purchase specifications
Material selections
Thread Lubricant Specifications

12.2 The following shall be submitted in accordance with Attachment A:

12.2.1 Drawings

12.2.1.1 Outline Drawings - A drawing depicting the outline of the reactor vessel indicating over-all dimensions, location and size of nozzles, location of supports, shipping and operating weights.

12.2.1.2 Assembly Drawings - A section drawing depicting the arrangement of the functional parts, parts list and material designation.

12.2.1.3 Detail Drawings - Drawings for details of construction such as weld preparations, surface finishes, finished dimensions, nozzles lifting attachments, insulation attachments, thermocouple pads, flanges and supports.

12.2.1.4 Drawings for Approval - Outline, assembly and detail drawings shall be submitted for approval. The detail drawings submitted shall be for design details enumerated in 12.2.1.3 which are required for coordination with piping and structure and design details which are at variance with the code or the requirements of this specification.

12.2.1.5 Controlling Location Arrangement Drawings

One or more drawings shall be devoted exclusively to outline dimensions such that mating components designed and supplied by others such as piping, anchor bolts, instruments, etc., may be procured for an exact fit with the reactor vessel assembly. These drawings shall show reference to the controlling detail drawings and show over-all dimensions and locations on reactor vessel.

12.2.1.6 Drawings to be Certified - Outline, Assembly and Detail drawings for design coordination shall, upon completion of the design, be certified to be correct with no further changes required. No alterations may be made to the design after certification without the approval of the Buyer.

12.2.2.5 Instructions and parts list shall be clearly legible and prepared on good quality paper; carbon copies and tissue copies or other flimsy material are not acceptable. Multiple page instructions shall be securely bound.

12.2.2.6 If a standard manual is furnished covering more than the specific equipment purchased, the applicable model (or other identification) parts and other information for the specific equipment purchased shall be clearly identified.

12.2.3 Photographs

The Seller shall provide the Buyer with sets of progress photographs of the vessel at each significant stage of fabrication. One set shall consist of one negative and three glossy 8" x 10" prints.

12.2.4 Engineering Schedule

12.2.5 Fabrication Schedule

12.3 Records

The Seller shall maintain records of all material qualifications, all weld and weldor qualifications and all process qualifications required by this specification and the material specifications. In addition, the Seller shall maintain records of all tests and inspections (e.g. - ultrasonic, radiography and hydrostatic). A list of the records shall be submitted to the Buyer on completion of the job. The Buyer shall be able to obtain certified copies of such records for a five-year period. Where the Seller considers the actual test records to be proprietary, he shall submit certified reports containing all pertinent test data excerpted from the actual test reports. These certified test reports shall also be available for a five year period.

ATTACHMENT A-1 INSTRUCTION MANUAL, DRAWING & DATA REQUIREMENTS

Review or approval of drawings, procedures, data, or specifications by the buyer with regard to general design and controlling dimensions does not constitute acceptance of any designs, materials, or equipment which will not fulfill the functional or performance requirements established by this specification and the purchase contract. Documents and drawings submitted shall be black line and of a quality which will produce readable prints when microfilmed (35 mm) and blown back on a conventional 18 x 24 printer viewer such as Filmac 200 or Itec. Send all documents and drawings to L.L. Kleinhesselink, GE, APED, (with copy of transmittal to APED Buyer, as indicated on the Purchase Order. All documents and drawings shall be identified with the appropriate Parts List Number(s).

DOCUMENT DESCRIPTION		No. REQUIRED & TYPE OF COPY	DUE
1. OUTLINE DIMENSIONS	Approval Certified	3 PRINTS + 1 REPRO 3 REPRODUCIBLE	* **
2. ASSEMBLY AND CROSS SECTION DRAWINGS WITH PARTS LIST WITH MATERIAL DESIGNATIONS	Approval Certified	3 PRINTS + 1 REPRO 3 REPRODUCIBLE	* **
3. DETAIL DRAWINGS	Approval Certified	3 PRINTS + 1 REPRO 3 REPRODUCIBLE	* **
4. CONTROLLING LOCATION-ARRANGEMENT AND DRAWINGS	Approval Certified	3 PRINTS + 1 REPRO 3 REPRODUCIBLE	* **
5. ENGINEERING SCHEDULE TO INCLUDE DATES FOR START AND FINISH FOR DESIGN CALCULATIONS, DATA, MATERIAL SELECTIONS, APPROVAL DRAWINGS AND DOCUMENTS.	Approval	1 REPRODUCIBLE	Within 20 days after award of order.
6. FABRICATION SCHEDULE WHICH DETAILS THE SEQUENCE OF FABRICATION, AND INDICATES START AND FINISH OF EACH PHASE.	Approval	1 REPRODUCIBLE	Within 30 days after award of order
7. DESIGN CALCULATIONS	Approval	6 COPIES	As completed but no later than 2 weeks prior to fabrication
8. ALL PROCEDURES & MAT'L PURCHASE SPEC. (EXCEPTION-SEE ITEM 12 BELOW)	Approval (Required Before Used)	6 COPIES	30 days prior to anticipated use
9. INSTRUCTION MANUALS	Approval	(Later) MANUALS (Later) MANUALS	120 days before ship. 30 days before scheduled shipping date
10. CODE CERTIFICATES		6 ORIGINAL COPIES	5 days after shipment
11. PHOTOGRAPH	Certified	3 PRINTS 1 NEGATIVE	At 2 month intervals
12. FABRICATION QUALIFICATION PROCEDURES		6 PRINTS	2 weeks prior to qualification tests
13. ADDITIONAL CALCULATION AND SUMMARY REPORT		6 COPIES, EA.	Upon completion of final design
14. ULTRASONIC, RADIOGRAPHIC & HYDROSTATIC INSPECTION & TEST REPORTS	Certified	8 COPIES	5 days after test

* Within 90 days after award of purchase contract and prior to fabrication.
** Within 30 days after receipt of approval drawings or within ______ days of receipt of purchase contract if approval drawings are not required.

PROJECT: MONTICELLO		DATE MAR - 5 1969	SH 1 CONT ON FINAL
BY: GT HAUGLAND	ISSUED: [illegible]	ATTACHMENT A TO SPEC.: [illegible]	REV NO. [illegible]

GENERAL ELECTRIC

ATOMIC POWER EQUIPMENT DEPARTMENT

PURCHASE SPECIFICATION

SPEC. NO. 21A1112 REV. NO. 3
SH NO. 1 CONT ON SHEET 2

ATTACHMENT B - MATERIAL TESTS AND TEST SPECIMENS

1.0 SCOPE

The Seller shall retain selected portions of the material used to fabricate the reactor vessel of this contract. He shall process some of this material into finished mechanical specimens which shall be in metallurgical conditions representative of the following as-fabricated reactor vessel material: Base-Plate, Welds and Heat-Affected Zone. The Seller shall test some of these specimens for "Fabrication Tests" to determine the effect of thickness on the mechanical properties of the material. The remainder of the specimens and the remainder of the selected test material shall be prepared for shipment. These latter specimens will be used for "Surveillance Tests" to monitor the effect of neutron irradiation on the mechanical properties of the reactor vessel steel.

2.0 FABRICATION TEST PROGRAM

2.1 Material

2.1.1 The fabrication test material shall be representative of the formed, heat-treated, and fully-fabricated reactor vessel, and shall be removed from one of the heats of plate material used in the reactor vessel construction, but need not necessarily be from a plate which becomes a part of the reactor vessel.

2.1.2 The fabrication test material shall be documented as to chemistry, thermal history, degree of hot and/or cold work, and welding.

2.2 Description

2.2.1 The Seller shall perform fabrication tests of base metal and welded joint. The results of the fabrication tests shall be reported during the early stages of reactor vessel construction. All of the fabrication test specimens shall be removed from the same plate.

2.2.2 The Seller shall make and test .505 inch diameter tensile specimens with the gage length in the tangential direction of the shell plate material. Tensile specimens shall be prepared from the O.D., 1/4T, 1/2T, and 3/4T thickness levels of the plate material. Each thickness level shall be tested at room temperature, 550°F, and 650°F per most recent ASTM Specifications E8 and E21. Three specimens shall be tested at each temperature for each thickness level. The tensile strength, yield strength, elongation, and reduction of area shall be reported.

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GENERAL ELECTRIC

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PURCHASE SPECIFICATION

SPEC. NO. 21A1112	REV. NO 3
SH NO. 2	CONT ON SHEET 3

ATTACHMENT B (CONT'D)

2.2.3 The Seller shall make and test, per most recent ASTM Specification E8, six tensile specimens whose gage diameter is at least 80% of the reactor vessel wall thickness.

2.2.3.1 The gage length to gage diameter ratio of the specimens shall be no less than 3 to 1. Tests shall be conducted at room temperature. Stress-strain curves, tensile strength, yield strength, elongation, reduction of area and macrophotographs of the breaks shall be reported for each specimen tested.

2.2.3.2 Where the reactor vessel wall courses are made from rolled plate with a longitudinal weld, three specimens shall be made from a base metal test plate with their gage lengths oriented to a vessel wall tangential direction and three specimens shall be made from a test plate simulating a vessel longitudinal weld with their gage lengths across the weld.

2.2.3.3 Where the reactor vessel wall courses are made of forged rings, three specimens shall be made from a base metal test plate with their gage lengths oriented to a vessel wall longitudinal direction and three specimens shall be made from a test plate simulating a vessel girth weld with their gage lengths across the weld.

2.2.4 The Seller shall make and test Charpy V-Notch impact specimens (ASTM E23, Type A) entirely from base material to establish curves for determining the 30 ft.-lb. transition temperature at the O.D., 1/4T, 1/2T, and 3/4T thickness levels of the plate material. The energy data, fracture appearance data and lateral expansion data for each individual specimen shall be reported. The data from each individual specimen shall be reported. There shall be at least six points reported within the 20 to 40 ft.-lb. range, and at least three testing temperatures represented within the range. In addition to the above the Impact Transition curves shall conform to Paragraph 10.2.4.

3.0 <u>SURVEILLANCE TEST PROGRAM</u>

3.1 <u>Base Metal - Figure 1</u>

3.1.1 The Seller shall furnish two plates, as shown in Figure 1, from the plate used to make the reactor vessel in the reactor core region, or from a similar plate from the same heat.

3.1.2 The Seller shall heat treat these plates with the reactor vessel, or in similar fashion, to insure that they represent the metallurgical condition of the vessel steel, in the core region of the completed reactor vessel including all post-weld heat treat cycles seen by that region.

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GENERAL ELECTRIC

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PURCHASE SPECIFICATION

SPEC. NO. 21A1112 REV. NO. 3
SH NO. 3 CONT ON SHEET 4

ATTACHMENT B (CONT'D)

3.1.3 The Seller shall furnish documents to the Buyer showing the location of the test plates and detailing all metallurgical data concerning the test plates.

3.1.4 The Seller shall make mechanical test specimens, as outlined below, from one of these plates and send the other to the Buyer.

3.2 Welded Plate - Figure 2

3.2.1 The Seller shall furnish a welded plate representative of a reactor vessel longitudinal weld, in the case of reactor vessels formed from plate or representative of a reactor vessel girth weld in the case of reactor vessels formed from forged rings, as shown in Figure 2, from the plate used to make the reactor vessel in the reactor core region, or from a similar plate from the same heat.

3.2.2 The Seller shall heat treat the plate with the reactor vessel, or in similar fashion, to insure that it and the weld represent the metallurgical condition of a vessel weld, in the core region of the completed reactor vessel including all post weld heat treatment cycles seen by that weld.

3.2.3 The Seller shall furnish documents to the Buyer showing the location of the test plates, detailing all metallurgical data and demonstrating that the weld was made in a manner similar to a reactor vessel weld. X-rays of the weld shall be furnished.

3.2.4 The Seller shall make mechanical test specimens, as outlined below, from half of the plate and shall supply the other half to the Buyer.

3.3 Surveillance Specimen Fabrication

3.3.1 The Seller shall provide a detailed plan of specimen preparation for the Buyer's approval prior to the start of any work required by this attachment. The Buyer can furnish a plan which the Seller may use as a guide. He shall be specific in indicating how the notch location of the Heat-Affected Zone Charpy specimens will be determined.

3.3.2 All specimen cutting shall be done by machining.

3.3.3 Specimen marking and mark orientation are of upmost importance. Each specimen shall be marked serially with the FAB Code series provided.

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PURCHASE SPECIFICATION

SPEC. NO. 21A1112	REV. NO. 3
SH NO. 4	CONT ON SHEET 5

ATTACHMENT B (CONT'D)

3.3.4 The Seller shall apply rust preventative to all specimens, shall arrange them in serial groups of like materials, and shall wrap them to prevent mechanical damage.

3.3.5 The Seller shall provide drawings showing all specimen locations with respect to the plate.

3.4 Preparation of Base Metal Charpy Test Specimens

(Refer to Figure 3 and Drawing 117B1549)

The Seller shall prepare 53 standard Charpy V-Notch impact specimens (ASTM E23, Type A, G.E. Drawing 117B1549) from the base plate material described in previous paragraphs. The specimens shall be taken from 1/4 thickness positions in the plate and at least 1T from any as-quenched edge. The long axes of the specimens shall be parallel to the plate rolling direction, or principal forging direction. The specimen notches shall be perpendicular to the original plate surface and shall be controlled by the orientation of the end marking on the specimen blanks.

3.5 Preparation of Base Metal Tensile Specimens

(Refer to Figure 3 and G.E. Drawing 117B1550)

The Seller shall prepare 14 1/4 inch gage diameter tensile specimens as per G.E. Drawing 117B1550, from the base plate material previously described. The specimens shall be taken from 1/4 thickness positions in the plate and at least 1T from any as-quenched edge. The long axes of the specimens shall be parallel to the plate rolling direction or principal forging direction.

3.6 Preparation of Weld Charpy Specimens

(Refer to Figure 4 and G.E. Drawing 117B1549)

The Seller shall prepare 53 Charpy impact specimens, per G.E. Drawing 117B1549 and Figure 4, from the weld deposit material of the furnished plate. The long axes of the specimens shall be perpendicular to the weld direction and parallel to the plate surface, with the middle of the specimen at the mid-plane of the weld, as shown in Figure 4. The specimen location in the stock material shall be recorded, approximately, by the numbering system. The notch shall be parallel to the plate surface and its orientation shall be controlled by the orientation of the marking symbols.

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PURCHASE SPECIFICATION

SPEC. NO. 21A1112 REV. NO. 3
SH NO. 5 CONT ON SHEET 6

ATTACHMENT B (CONT'D)

3.7 Preparation of Weld Tensile Specimens

(Refer to Figure 5 and G.E. Drawing 117B1550)

The Seller shall prepare 13 tensile specimens, per G.E. Drawing 117B1550 from the weld deposit material of the furnished plate. The long axes of the specimens shall be parallel to the length of the weld and parallel to the top surface of the plate (See Figure 5). The gage length of the specimens shall be of weld-deposit metal only. The treaded ends of the specimens may include Heat-Affected Zone or base metal. The approximate location of the specimens in the stock material shall be recorded by the marking system.

3.8 Preparation of Heat-Affected Zone Tensile Specimens

(Refer to Figure 6 and G.E. Drawing 117B1550)

The Seller shall prepare 13 tensile specimens, per G.E. Drawing 117B1550, from the welded material of the furnished plate. The long axes of the specimens shall be perpendicular to the length of the weld and parallel to the top surface of the plate (See Figure 6). The center of the specimen shall be in the Heat-Affected Zone adjacent to the edge of the weld metal. The approximate location of the specimens in the stock material shall be recorded by the marking system.

3.9 Preparation of Heat-Affected Zone Charpy Specimens

(Refer to Figure 7 and G.E. Drawing 117B1549)

The Seller shall prepare 53 Charpy specimens, per G.E. Drawing 117B1549, from the welded material of the furnished plate. The long axes of the specimens shall be perpendicular to the length of the weld and parallel to the top surface of the plate (See Figure 7). The radius of the notch of the specimen shall be at one outer edge of the weld. The axis of the notch shall be perpendicular to the original plate surface. The notch orientation shall be controlled by the marking orientation. The location of the specimen in the stock material shall be recorded, approximately, by the marking system.

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SPEC. NO. 21A1112 REV. NO. 3
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ATTACHMENT B (CONT'D)

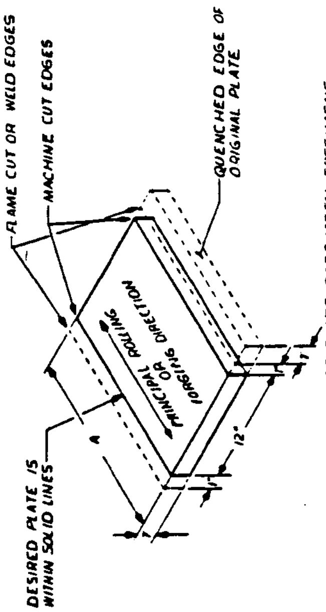

FIGURE 1: TEST PLATE-BASE METAL SPECIMENS

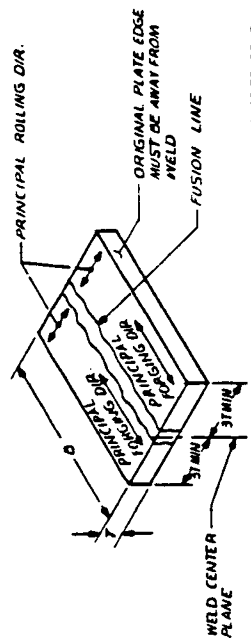

FIGURE 2: TEST WELD FOR WELD AND HEAT AFFECTED ZONE SPECIMEN (SIMULATES LONGITUDINAL WELDS FOR PLATE AND GIRTH WELDS FOR FORGINGS)

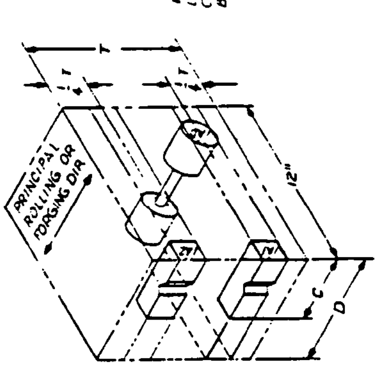

FIGURE 3: BASE METAL CHARPY AND TENSILE SPECIMEN LOCATION

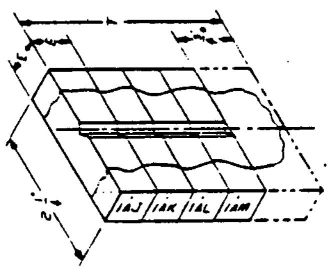

FIGURE 4: WELD CHARPY

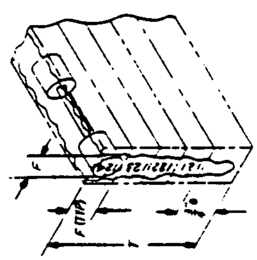

FIGURE 5: WELD TENSILE

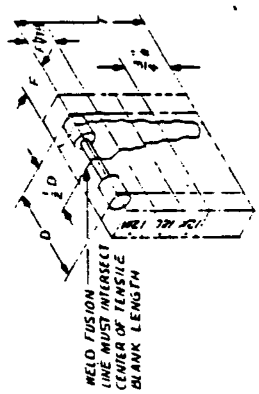

FIGURE 6: HEAT AFFECTED ZONE TENSILE

NOTES:

A- 30" MIN: THIS DIMENSION MAY BE FURNISHED BY 2 OR 3 SMALLER PIECES.

B- 4 FT MIN: SEVERAL PIECES CAN BE JOINED TO MAKE THIS DIMENSION HOWEVER WELD MUST BE CONTINUOUS.

C- CHARPY BLANK LENGTH

D- TENSILE BLANK LENGTH

E- CHARPY BLANK THICKNESS

F- TENSILE BLANK THICKNESS

T- VESSEL WALL THICKNESS

•- THIS ⅛ INCH DISCARDED MATERIAL SHOULD BE LOCATED SO AS TO COMPLETELY REMOVE FROM TEST THE AREA OF A WELD WHICH CONTAINS THE MATING SURFACES OF THE WELD PREP. IN THE CASE OF A SINGLE "J" GROOVE IT WILL BE AS SHOWN IN FIG 4. IN THE CASE OF A DOUBLE "J" OR "V" GROOVE IT MIGHT BE LOCATED IN THE CENTER OF THE WELD.

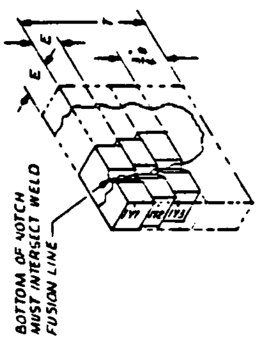

FIGURE 7: HEAT AFFECTED ZONE CHARPY

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ATTACHMENT C

DESIGN ANALYSIS SCHEDULE
FOR
REACTOR PRESSURE VESSEL FOR MONTICELLO POWER STATION

BOLTING AND CLOSURE FLANGES

Tasks	ASME Section III Stress Category	Responsible Party	SCHEDULE 1966 A	S	O	N	D	1967 J	F	M	A	M	J	J	A	S
(Total Task Time)																
Sizing, ASME Code Calculations	P_M, P_L, Q	CB&I														
Drawings and Dimensions		CB&I														
Loads - Pressure, Temperature		GE														
Thermal Analysis																
Steady State		GE														
Transient		GE														
Stress and Flange Rotation Analysis																
Analytical Model & Methods		CB&I														
Hydro & Design P	P_M, P_L, P_B, Q	CB&I														
Bolt Preload	P_M	CB&I														
Transient Heatup and Shutdown	Q	GE														
Fatigue Analysis	F	GE														
Review and Approval		GE														

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ATTACHMENT C (CONT'D)

DESIGN ANALYSIS ..HEDULE
FOR
REACTOR PRESSURE VESSEL FOR MONTICELLO POWER STATION

BOTTOM HEAD AND SUPPORT SKIRT

Tasks	ASME Section III Stress Category	Responsible Party	SCHEDULE 1966: A S O N D / 1967: J F M A M J J A S
(Total Task Time)			
Sizing, ASME Code Calculations	P_M, P_L, Q	CB&I	
Drawings and Dimensions		CB&I	
Loads - Pressure, Temperature Seismic Weight Jet Forces		GE	
Analytical Model		CB&I	
Seismic Analysis		CB&I	
Thermal Analysis		GE	
Stress Analysis	P_M,P_B,P_L,Q	GE	
Fatigue Analysis	F	GE	
Review and Approval		GE	

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DESIGN ANALYSIS SCHEDULE
FOR
REACTOR PRESSURE VESSEL FOR MONTICELLO POWER STATION

:RD PENETRATION

Tasks	ASME Section III Stress Category	Responsible Party	SCHEDULE 1966 A	S	O	N	D	1967 J	F	M	A	M	J	J	A	S
(Total Task Time)																
Drawings and Dimensions		CB&I														
Sizing, ASME Calculation		CB&I														
Loads - Seismic, Scram Weights, Pressure Flow Rates and Temperatures		GE														
Thermal Analysis - Steady State Transient		GE														
Stress Analysis - Primary	P_M, P_L, P_B	CB&I														
Primary and Secondary	P_M, P_L, P_B, Q	GE														
Fatigue Analysis	P_M, P_L, P_B, Q, F	GE														
Review and Approval		GE														

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ATTACHMENT C (CONT'D)

DESIGN ANALYSI[illegible] [illegible]HEDULE
FOR
REACTOR PRESSURE VESSEL FOR MONTICELLO POWER STATION

NOZZLES*

Tasks	ASME Section III Stress Category	Responsible Party	SCHEDULE: 1966 A S O N D – 1967 J F M A M J J A S
(Total Task Time)			
Drawings and Dimensions		CB&I	
Sizing, ASME Calculations		CB&I	
Loads - Pipe Reactions - Seismic - Pressures - Flow Rates and Temperatures		GE	
Thermal Analysis - - Steady State - Transient		GE	
Stress Analysis -Primary	P_M, P_L, P_B	CB&I	
-Primary and Secondary	P_M, P_L, P_B, Q	GE	
Fatigue Analysis	P_M, P_L, P_B, Q, F	GE	
Review and Approval		GE	

* Note breakdown of nozzles to be analyzed per this schedule on page 6.

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ATTACHMENT C (CONT'D)

DESIGN ANALYSIS SCHEDULE
FOR
REACTOR PRESSURE VESSEL FOR MONTICELLO POWER STATION

Tasks	ASME Section III Stress Category	Responsible Party	SCHEDULE 1966 A	S	O	N	D	1967 J	F	M	A	M	J	J	A	S
(Total Task Time)																
SHROUD SUPPORT																
Sizing, ASME Code Calculations		CB&I														
Drawings and Dimensions		CB&I														
Loads - Pressure, Temperature, Seismic, Weights and Forces		GE														
Stress Analysis	P_M, P_L, P_B	CB&I														
Review and Approval		GE														
(Total Task Time)																
REFUELING BELLOWS SUPPORT SKIRT																
Sizing		CB&I														
Drawings and Dimensions		CB&I														
Loads - Weight, Temperature		GE														
Thermal Analysis		CB&I														
Stress Analysis	P_M, P_B, P_L, Q	CB&I														
Fatigue Analysis	F	CB&I														
Review and Approval		GE														

MAR - 5 1969

DESIGN ANALYSI .CHEDULE
FOR
REACTOR PRESSURE VESSEL FOR MONTICELLO POWER STATION

Tasks	ASME Section III Stress Category	Responsible Party	1966 A	S	O	N	D	1967 J	F	M	A	M	J	J	A	S
ANALYTICAL REWORK																
CB&I at APED for an estimated three trips		GE														
FINAL REPORT		CB&I														

* The nozzle schedule on page 4 is for the following nozzles:

(1) Core spray and flooding
(2) Feedwater
(3) Control Rod Hydraulic Return
(4) Core differential pressure and liquid control
(5) Recirc Inlet
(6) Recirc Outlet
(7) Steam Outlet

CB&I is responsible for the complete analysis of

(1) All nozzles not specified above
(2) Stabilizer brackets
(3) Insulation brackets
(4) Head lifting lugs
(5) Shroud head and dryer guide support
(6) Feedwater sparger support
(7) Any other internal vessel attachments

21A1112, Rev. 0
Sh 6 Cont. on F

MAR -5 1969

TEMPERATURE TRAI. .ENTS

Vessel Part	No. of Cycles	Fluid Temp. Rate	Fluid Start Temp.	Fluid End Temp.	State of Fluid	Fluid Velocity	Vessel Pressure	Notes
Recirc. Outlet	200	100 F/hr	100	546	Water	25 ft/sec	Saturated	
	200	1000 F/hr 100 F/hr	546 370	370 100	Water	25 ft/sec	Saturated	Followed by
	5	Step	546 (Step to 130)	546 (Step from 130)	Water	5 ft/sec (reverse flow)	1000 psig	26 seconds duration at 130°F
Recirc. Inlet Nozzle	200	100 F/hr	100	546	Water	32 ft/sec	Saturated	
	200	0 0	546 90	546 90	Water Water	32 ft/sec 10 ft/sec	 170 psig	Followed by
Steam Outlet Nozzle	532	100 F/hr	100	546	Steam	5 ft/sec	Saturated	Condensing Steam in nozzle
	531	100 F/hr 1000 F/hr 100 F/hr	546 346 296	346 296 100	Steam Water Water	5 ft/sec 14 ft/sec 0	Saturated Saturated Saturated	Followed by Followed by
	1	1000 F/hr 100 F/hr	546 370	370 100	Steam Steam - Water	25 ft/sec 0	Saturated Saturated	Followed by
Feedwater Nozzle		0	376	376	Water	10 ft/sec	1100 psig	Steady State 546° Water in Vessel
	1500	100 F/hr 0 250 F/hr	100 100 260	546 100 376	Water Water Water	0 5 ft/sec 5* ft/sec	1100 psig 1100 psig 1100 psig	Followed by Step To Followed by Step To
Core Spray Nozzle	250	100 F/hr	100	546	Water	0	Saturated	
	250	0	546 80 **	80	Water Water	0 20 ft/sec	1000 psig 0 psig	Followed by (Steam in Thermal Sleeve Annulus)

* Velocity changes linearly 5 ft/sec to 20 ft/sec

** Water reaches this temperature in 15 seconds

ATTACHMENT D

Sht. 1 Cont. on 2.

MAR - 5 1969

TEMPERATURE TRA ENTS

Vessel Part	No. of Cycles	Fluid Temp. Rate	Fluid Start Temp.	Fluid End Temp.	State of Fluid	Fluid Velocity	Vessel Pressure	Notes
Jet Pump Instrument Nozzles	200	1000 F/hr 100 F/hr	546** 370	370 100	Water	0 0	Saturated Saturated	Followed by
CRD Hydraulic Return Nozzle	200	0	45°	45°	Water	15 ft/sec	1000 psig	Steady State 546° Water in vessel
Core Diff. & Liquid Control Nozzle	10	0	80 ***	80 ***	Water	15 ft/sec ***	1000 psig	Nozzle at 546°** Isothermal at Start
	200	1000 F/hr 100 F/hr	546** 370	370 100	Water Water	0 0	Saturated Saturated	Followed by
2 Inch Instrument Nozzle	200	100 F/hr	330	100	Water	0	Saturated	Nozzle at 546° Isothermal at Start
	200	1000 F/hr 100 F/hr	546** 370	370 100	Water	0 0	Saturated Saturated	Followed by
Core Support Structure	200	100 F/hr	100	546	Water	5 ft/sec*	Saturated	
	199	100 F/hr 1000 F/hr 100 F/hr	546 346 296	346 296 100	Water Water Water	5 ft/sec* 5 ft/sec* 5 ft/sec*	Saturated Saturated Saturated	Followed by Followed by
	1	1000 F/hr 100 F/hr	546 370	370 100	Water	5 ft/sec*	Saturated	Followed by
	Water is on all sides of Core Support structure and on inside surface of Reactor Vessel for both the above transients.							
	5	Step	546 Step to 130	546 Step from 130	Water	See Recirc Outlet	1000 psig	26 seconds duration of 130°F

* Water velocity above the support plate, on the vertical surface of the shroud cylinders, and on the underside of the support plate is essentially zero and natural convection heat transfer coefficient may be used. The 5 ft/sec velocity is directed against the vessel bottom head but by using natural convection heat transfer coefficients a conservative analysis should result.

** Water reaches this temperature at a fluid temperature rate of 100F/hr.

*** See 886D482, Sht. 3 for location of liquid control flow.

MAR - 5 1969

ATTACHMENT D

TEMPERATURE TRANSIENTS

Vessel Part	No. of Cycles	Fluid Temp. Rate	Fluid Start Temp.	Fluid End Temp.	State of Fluid	Fluid Velocity	Vessel Pressure	Notes
Closure Flanges & Adjacent Shell and Refueling Bellows Support Skirt	200	100 F/hr	100	546	Steam	0	Saturated	Condensing Steam Heat Transfer
	199	100 F/hr	546	350	Steam		Saturated	Followed by
		Flooding with water at 330°F				Free		Followed by
		100 F/hr	300	150	Water	Conv.	Saturated	
	1	1000 F/hr	546	375	Steam	Free	Saturated	Followed by
		100 F/hr	375	100	Steam	Conv.	Saturated	
Bottom Head & Support Skirt	200	100 F/hr	100	546	Water	5 ft/sec	Saturated	
	199	100 F/hr	546	375	Water	5 ft/sec	Saturated	Followed by
		300 F/hr	375	330	Water	5 ft/sec	Saturated	Followed by
		100 F/hr	330	100	Water	5 ft/sec	Saturated	
	1	1000 F/hr	546	370	Water	5 ft/sec	Saturated	Followed by
		100 F/hr	370	100	Water	5 ft/sec	Saturated	
Control Rod Drive Penetration Peripheral Location and Central Location	370	0	50°	50°	Water	* 10 ft/sec outside assembly	1000 psig	Penetration Assembly at 546° at Start
		*Heat transfer coefficients through a thermal sleeve within the housing are: (a) h = 75 Btu/hr ft^2°F above stub tube (b) h = 193 Btu/hr ft^2°F at stub tube (c) h = 40 Btu/hr ft^2°F below stub tube						

NOTE: For the purposes of demonstrating for other parts of the vessel applicable exception from Detailed Stress Analysis according to Paragraphs N-415.1 and N-451 of the ASME Code Section III, the following values may be used.

(a) Total design pressure cycles from atmospheric pressure to operating pressure and back to atmospheric pressure is 200 cycles.

(b) The number of significant pressure fluctuations (200 psi full range) during normal operation is 280.

(c) The number of major temperature fluctuations is 400

ATTACHMENT D

MAR - 5 1969

GENERAL ELECTRIC
ATOMIC POWER EQUIPMENT DEPARTMENT

PURCHASE SPECIFICATION

ad

SPECIAL PROJECT MONTICELLO	
SPEC. NO. 21A1112	REV. NO. 1
SH NO. 1	CONT ON SHEET F

TITLE

REACTOR PRESSURE VESSEL

ATTACHMENT E

CERTIFICATION OF DESIGN SPECIFICATION AS TO COMPLIANCE WITH THE REQUIREMENT OF THE ASME BOILER AND PRESSURE VESSEL CODE SECTION III NUCLEAR VESSELS

This Specification 21A1112, Rev. 6, lists for the Monticello Nuclear Power Station the purchase specification, specification control drawings, and supplementary specifications which comprise the Design Specifications required by Paragraph N-141 of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Vessels.

This certification is issued in order that design and fabrication of the reactor pressure vessels identified by General Electric Company Purchase Order 205-55582-I may proceed in accordance with the requirements of Section III.

Pursuant to Paragraph N-140 of Section III, this certification is solely for the purpose of complying with the requirements of ASME Boiler and Pressure Vessel Code, Section III, and is not to be construed as involving, modifying or changing contractual relations or legal liabilities.

CERTIFIED BY R L Call DATE March 4, 1969
Registered Professional Engineer

STATE California BRANCH Mechanical NO. 13540

REFERENCE DRAWINGS AND DOCUMENTS

NUMBER	DESCRIPTION
886D482, Rev. **	Reactor Vessel Specification Control
885D911, Rev. 2	Vessel Flange Bolting
107C5305, Rev. 2	Nozzle End Preparation
21A9821, Rev. 0	Stud Tensioners
117B1549, Rev. 2	Charpy Impact Specimen
117B1550, Rev. 2	1/4" Tensile Test Specimen
21A1050, Rev. 0	Reactor Servicing Tools
Attachment B, Rev. 3	Material Test and Test Specimens
Attachment D, Rev. 1	Temperature Transients
♠ 731E678, Sht. 1, Rev. 0	Vessel As-Built Dimensions
731E678, Sht. 2, Rev. 0	Vessel As-Built Dimensions

REGISTERED PROFESSIONAL ENGINEER
R. L. CALL
No. 13540
3-4-69
MECHANICAL
STATE OF CALIFORNIA

** Sht. #	Rev. #	Sht. #	Rev. #
1	5	5	3
2	10 ♠	6	4 ♠
3	2 ♠	7	9 ♠
4	7 ♠	8	3

MAR - 1969

BY:	ISSUED:
DR HEISING	JA MAST

EXHIBIT 2

MANUFACTURER'S DATA REPORT AND VESSEL CERTIFICATION

PRESSURE VESSEL REPORT

MANUFACTURER'S DATA REPORT
AND VESSEL CERTIFICATION

MONTICELLO

GENERAL ELECTRIC CO.
APED - SAN JOSE

VPF# 1811-355-1

EP# 2-1-1

PRESSURE VESSEL RECORD

MANUFACTURER'S DATA REPORT AND CERTIFICATIONS

BOILING WATER NUCLEAR REACTOR VESSEL
17.167' x 63.167' INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697.
MONTICELLO PROJECT, MONTICELLO, MINN.
G.E. CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

TABLE OF CONTENTS

17. Nameplate Photograph

18. Fabrication Test Program Certification

19. Results of Tensile Tests per Par. 2.2.2 Attachment B

20. Results of Charpy V-Notch Impact Tests per Par. 2.2.4 Attachment B

TJA
10/2/68

FORM N-1 MANUFACTURERS DATA REPORT FOR NUCLEAR VESSELS

As required by the Provisions of the ASME Code Rules CB&I Contract No. 9-5624

1. Manufactured by Chicago Bridge & Iron Company, Birmingham, Alabama (Name and address of Manufacturer)
2. Manufactured for General Electric Co. For Northern States Pwr. Co., Monticello, Min. (Name and address of Purchaser)
3. Type Vert. (Horiz. or Vert.) Kind Nuclear Reactor (Tank, Jacketed, Heat Ex.) Vessel No. (B-4697) (Mfrs. Serial No.) ( ) (State & State No.) Nat'l Bd. No. ...... Yr. Built 1969

Items 4-8 incl. to be completed for single wall vessels, jackets of jacketed vessels, or shells of heat exchangers.

*4. Shell: Material See S1 below (Kind & Spec. No.) T.S. 80,000 (Min. of range specified) Nominal Thickness See S2 Below 5.063 in. Corrosion Allowance 1/16 in. Diam. (outs.) ins. hd/ins. hd. 17 ft. 2 in. Length 63 ft. 2 in.

5. Seams: Long Dbl. Butt weld H.T.[1] Yes X.R. Complete Efficiency 100 %

Girth Dbl. Butt weld H.T.[1] Yes X.R. Complete No. of Courses ......

*6. Heads: (a) Material See S1 Below T.S. 80,000 (b) Material See S1 Below T.S. 80,000

Location (Top, bottom, ends)	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Press. (Convex or Concave)
(a) Bottom	5.063,5.938	(See S2 below)				8'-7"		Concave
(b) Top	2.688,3.250	(See S2 Below)				8'-7"		Concave

If removable, bolts used Top Hd. Studs & Nuts: ASTM A540 GR. B23 to C.C. 1335-2, CL3, 145,000, 5.0625, 64 (Material, Spec. No., T.S., Size, Number)

7. ~~Jacket Closure~~ Main Closure Flg: ASTM A508 CLII with .125 Min. Thk. S.S. overlay

8. Constructed for operating press.[2] 1000 psi at Max. temp. 575 °F Charpy Impact 30 ft-lb at temp. of 40 °F. ~~Pneumatic~~ Hydrostatic or ~~Combination~~ Field Test Pressure 1563 psi at Btm. Vessel "0"

Items 9 and 10 to be completed for tube sections.

9. Tube Sheets: Stationary. Material ...... (Kind & Spec. No.) Diam. ...... (Subject to press.) in. Thickness ...... in. Attachment ...... (Welded, Bolted)

Floating. Material ...... (Kind & Spec. No.) Diam. ...... in. Thickness ...... in. Attachment ......

10. Tubes: Material ...... (Kind & Spec. No.) O.D. ...... in. Thickness ...... inches or gage Number ...... Type ...... (Straight or U)

Items 11 to 14 incl. to be completed for inner chambers of jacketed vessels, or channels of heat exchangers.

11. Shell: Material ...... (Kind & Spec. No.) T.S. ...... (Min. of range specified) Nominal Thickness ...... in. Corrosion Allowance ...... in. Diam. ...... ft. ...... in. Length ...... ft. ...... in.

12. Seams: Long ...... (Welded, Dbl., Single) H.T.[1] ...... (Yes or No) X.R. ...... Efficiency ...... (If Class B) %

Girth ...... H.T.[1] ...... X.R. ...... No. of Courses ......

13. Heads: (a) Material ...... T.S. ...... (b) Material ...... T.S. ...... (c) Material ...... T.S. ......

Location	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Press. (Convex or Concave)
(a) Top, bottom, ends								
(b) Channel								
(c) Floating								

If removable, bolts used (a) ...... (b) ...... (c) ...... (Material, Spec. No., T.S., Size, Number) Other fastening ...... (Describe or attach sketch)

14. Constructed for specified operating press.[2] ...... psi at Max. temp. ...... °F Charpy Impact ...... ft-lb at temp. of ...... °F Pneumatic Hydrostatic or Combination Test Pressure ...... psi

[1] If Postweld Heat-Treated.

[2] List other internal or external pressures with coincident temperature when applicable.

*Items S1 and S2 are supplementary information to Items 4 and 6

S1. Shell and head Material: ASTM Spec. A533 Cl. 1, Grade B Firebox backing with .125 min. thk. stnls stl. weld overlay.

S2. Thicknesses shown are min. base metal thicknesses and do not include the .125 min. overlay thickness. Vessel radii and diameters are shown to the inside surface of the overlay.

FORM N-1 (back)

Items below to be completed for all vessels where applicable.

15. Safety Valve Outlets: Number .... Size .... Location Unknown

16. Nozzles: a) Shop Installed b) Field Installed

Purpose (Inlet, Outlet, Drain)	Number	Diam. or Size	Type	Material	Thickness	Reinforcement Material	How Attached
a) See Dwg. N1	29	2" to 36"			5/8 to 7-1/4	Integral	Welded
b) See Dwg. N1	7	1", 12"2			3/8, 1/2"	Integral	Welded

17. Inspection Openings: Manholes, No. .... Size .... Location Top Head Removable
Handholes, No. .... Size .... Location ....
Threaded, No. .... Size .... Location ....

18. Supports: Skirt Yes X (Yes or No) Lugs .... Legs .... Other .... Attached Welded-Bottom Head (Where & How)

19. Remarks: a) Service - Nuclear Reactor Vessel
b) Fabrication Information: (1) All plates formed and overlaid at Birmingham Plant. (2) Bottom head subassemblies formed and welded at Birmingham and sent to Greenville for additional fabrication - See Form N-2 attached. (3) All nozzles to be fab. at Birmingham. (4) All long & girth seams in the cylindrical portion, incl. overlay, to be made in field. (5) Field to machine main closure flgs. & bottom head.
(Brief description of service for which vessel was designed)

CERTIFICATION OF DESIGN

Design information on file at Chicago Bridge & Iron Co., Birmingham, Alabama
Stress analysis report on file at Chicago Bridge & Iron Co., Birmingham, Alabama
Design specifications certified by R. L. Call Prof. Eng. Yes State Cal. Reg. No. 13540
Stress analysis report certified by R. F. Ready Prof. Eng. Yes State Ill. Reg. No. 62-21203

We certify that the statements made in this report are correct and that all details of material, design, construction, and workmanship of this pressure vessel conform to the ASME Code for Nuclear Vessels.

Date 10-8 1968 Signed Chicago Bridge & Iron (Manufacturer) By Ellis Treadaway Shop
Certificate of Authorization Expires Dec. 31, 1970 Co. By: W. R. Wagner Field

CERTIFICATE OF SHOP INSPECTION

VESSEL MADE BY Chicago Bridge & Iron Company at Birmingham, Alabama

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State of NE and employed by HSB I & I Co of Hartford Conn have inspected the pressure vessel described in this manufacturer's data report on 10-7 1968, and state that to the best of my knowledge and belief, the manufacturer has constructed this pressure vessel in accordance with the ASME Code for Nuclear Vessels.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this manufacturer's data report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 10-7 1968

William A. White (Inspector's Signature) Commissions NC 211 (National Board or State and No.)

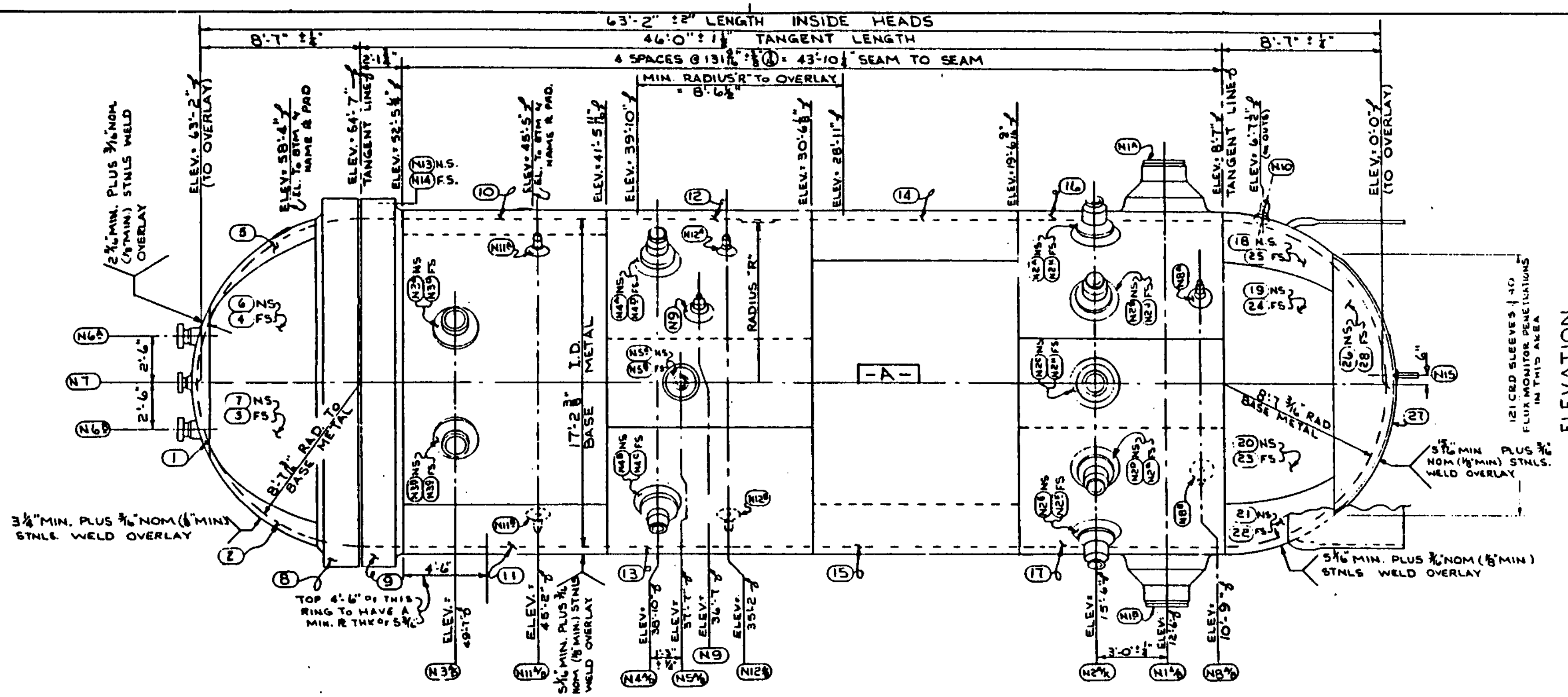
CERTIFICATE OF FIELD ASSEMBLY INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State of .... and employed by The Hartford Steam Boiler Insp. & Ins. Co. of Hartford Conn. have compared the statements in this manufacturer's data report with the described pressure vessel and state that parts referred to as data items 5, 16b, 18, 19 ...., not included in the certificate of shop inspection have been inspected by me and that to the best of my knowledge and belief the manufacturer has constructed and assembled this pressure vessel in accordance with the ASME Code for Nuclear Vessels. The described vessel was inspected and subjected to a hydrostatic test of 1563 psi.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this manufacturer's data report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 2-21 1967

Harold Ayer (Inspector's Signature) Commissions Wisconsin #18 (National Board or State and No.)



NOZZLE	QUAN	SIZE	FUNCTION	AZIMUTH ±0°	DIST. FROM VESSEL "O" ±	TYPE	MATERIAL	NECK THICKNESS	REINF. MATERIAL	HOW & WHERE ATTACHED	MFG. DATA REPORT	SS. OLAY
N1A & N1B	2	36x28	RECIRCULATION OUTLET	A=0°, B=180°	150"	STUB	A508 CL. II	1 7/16" - 10¼"		WELDED-SHOP	N1 #16(a)	YES
N2A THRU N2K	10	12"	RECIRCULATION INLET	A=30°, B=60°, C=90°, D=120°, E=150°,	186"	DO.	DO.	⅞" - 7¼"		DO.	DO.	YES
				F=210°, G=240°, H=270°, J=300°, K=330°								
N3A THRU N3D	4	18"	STEAM OUTLET	A=72°, B=108°, C=252°, D=288°	595"	STUB	DO	1¼" - 7"		DO.	DO.	NO
N4A THRU N4D	4	10"	FEEDWATER	A=45°, B=135°, C=225°, D=315°	466"	DO	DO.	⅝" - 6⅛"		DO.	DO.	NO
N5A & N5B	2	8"	CORE SPRAY	A=90°, B=270°	451"	DO	DO.	⅞" - 6¼"		DO.	DO	YES
N6A & N6B	2	6"	HEAD SPRAY & INSTR.	A=0°, B=180° ON TOP HD @ 30"R.	—	FLANGE	DO.	1⅝" - 2¾"		DO.	DO.	YES
N7	1	4"	VENT	TOP DEAD CENTER	—	DO.	DO.	1¼" - 1 5/16"		DO.	DO	YES
N8A & N8B	2	4"	JET PUMP INST.	A=60°, B=240°	129"	STUB	DO	⅞" - 3 7/16"		DO	DO	YES
N9	1	3"	CRD HYD SYS. RETURN	65°	439"	DO.	DO.	⅞" - 4"		DO.	DO.	YES
N10	1	2"	CORE DIFF. PRESS & LIQ CONT	350°	79½"	DO	DO	⅞" - 2¼"		DO.	DO	YES
N11A & N11B	2	2"	INSTRUMENTATION	A=40°, B=220°	542"	DO	SB166 MOD	½"		WELDED - FIELD	N1 #16(b)	NO
N12A & N12B	2	2"	DO.	A=40°, B=220°	422"	DO.	DO	½"		DO	DO.	NO
N13	1	1"	HIGH PRESS. LEAK DET.	BETWEEN HD BOLTS 0° APPROX	—	FEMALE SOCKET WELDING CPLG.	SB167	—	—	DO.	DO	NO
N14	1	1"	LOW PRESS. LEAK DET.	DO , 5° APPROX	—	DO.	DO.	—	—	DO.	DO.	NO
N15	1	2"	DRAIN	SEE BOTTOM HEAD	—	STUB	A508 CL. II	.726	E8018 NM	DO	DO	NO
S1 THRU S20	121	6"	C.R.D. SLEEVES	DO.	—	—	—	—	—	—	—	—
P1 THRU P14	40	2"	FLUX MONITOR	DO.	—	PENET. ONLY	—	—	—	—	—	—

CHICAGO BRIDGE & IRON COMPANY

SUPPLEMENTARY SHEET FOR MANUF. DATA REPORT - FORM N1
17'-2 ID x 63'-2 INS. HDS NUCLEAR REACTOR FOR GEN. ELEC. CO FOR NORTHERN STATES PWR. CO. MONTICELLO, MINN.

PURCHASER'S NO 205-55568-1 CONTRACT NO 9-5624

DRAWN BY R.E.H. DATE 2-11-65

CHECKED BY T.B. DATE 2-12-65

H.L. WAILES
ENGINEERING COORDINATOR

DWG N1 REV 0

FORM N-2 MANUFACTURERS' PARTIAL DATA REPORT

A Part of a Nuclear Vessel Fabricated by One Manufacturer for Another Manufacturer
As required by the Provisions of the ASME Code Rules

TJA
9/3/68

1. (a) Manufactured by CHICAGO BRIDGE & IRON CO., GREENVILLE, PENNSYLVANIA
(Name and address of manufacturer of part)

(b) Manufactured for CHICAGO BRIDGE & IRON CO., BIRMINGHA., ALABAMA (SEE 3C)
(Name and address of manufacturer of completed nuclear vessel)

2. Identification-Manufacturer's Serial No. of Part Reactor Vessel Serial No. - B4697

(a) Constructed According to Drawing No. 32 & 33 Drawing Prepared by CB&I (CONT. No. 9-5624)

(b) Description of Part Inspected Bottom head side plate assembly and dollar plate
Greenville shop work consists of items 3A, B & C only.

3. Remarks: A) Bottom head hemispherical segment: Machining of edges and selected overlay areas.

B) Dollar plate: Prebore 121 CRD penetrations and 40 incore penetrations, scarf and weld deposit overlay around CRD penetrations, machining edges

C) Assemblies will be shipped from Greenville, Pa. directly to the field site at Monticello, Minnesota.
(Brief description of service for which vessel part was designed)

We certify that the statements made in this report are correct and that all details of material, design, construction, and workmanship of this pressure vessel conform to the ASME Code for Nuclear Vessels

Date 10-2 1968 Signed Chicago Bridge & Iron Co Howard L. Aubel
(Manufacturer)

Certificate of Authorization Expires Dec. 31,1970

CERTIFICATION OF DESIGN

Design information on file at Chicago Bridge & Iron Co., Birmingham, Alabama

Stress analysis report on file at Chicago Bridge & Iron Co., Birmingham, Alabama

Design specifications certified by R. L. Call Prof. Eng. Yes State Cal Reg. No. 13540

Stress analysis report certified by R. F. Reedy Prof. Eng. Yes State Ill. Reg. No. 62-21203

CERTIFICATE OF SHOP INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State of Pa. and employed by Hartford Stm. Blr. Insp. & Ins. Co. of Hartford Conn. have inspected the part of a pressure vessel described in this manufacturer's partial data report on 10-31- 1967, and state that to the best of my knowledge and belief, the manufacturer has constructed this part in accordance with the ASME Code for Nuclear Vessels.

By signing this certificate, neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the part described in this manufacturer's partial data report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 10-2 1968

G. M. Vuksan
Inspectors Signature

Commissions PA 1762
National Board or State and No.

60 181

FORM N-2 (back)

Items 4-8 incl. to be completed for single wall vessels, jackets of jacketed vessels, or shells of heat exchangers.

4. Shell: Material .... (Kind & Spec. No.) T.S. .... (Min. of Range specified) Nominal Thickness .... in. Corrosion Allowance .... in. Diam. .... ft .... in. Length .... ft .... in.

5. Seams: Long .... H.T.[1] .... X.R. .... Efficiency (If Class B) .... %

Girth .... H.T.[1] .... X.R. .... No. of Courses ....

6. Heads: (a) Material See N-1.6(a) T.S. .... (b) Material .... T.S. ....

Location (Top, bottom, ends)	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Press. (Conv. or Conc.)
(a) See N-1.6(a)								
(b)								

If removable, bolts used .... (Material, Spec. No., T.S., Size, Number) Other fastening .... (Describe or attach sketch)

7. Jacket Closure: .... (Describe as ogee and weld, bar, etc. If bar give dimensions, if bolted, describe or sketch).

Charpy Impact .... ft-lb

8. Constructed for specified operating pressure[2] .... psi at max. temp. .... °F at temp. of .... °F

Items 9 and 10 to be completed for tube sections.

9. Tube Sheets: Stationary. Material .... (Kind & Spec. No.) Diam .... (Subject to pressure) Thickness .... in. Attachment .... (Welded, Bolted)

Floating. Material .... Diam .... Thickness .... in. Attachment ....

10. Tubes: Material .... O.D. .... in. Thickness .... inches or gage. Number .... Type .... (Str. or U)

Items 11-14 incl. to be completed for inner chambers of jacketed vessels, or channels of heat exchangers.

11. Shell: Material .... (Kind & Spec. No.) T.S. .... (Min. of Range specified) Nominal Thickness .... in. Corrosion Allowance .... in. Diam .... ft .... in. Length .... ft .... in.

12. Seams: Long .... H.T.[1] .... X.R. .... Efficiency (If Class B) .... %

Girth .... H.T.[1] .... X.R. .... No. of Courses ....

13. Heads (a) Material .... T.S. .... (b) Material .... T.S. ....

Location	Thickness	Crown Radius	Knuckle Radius	Elliptical Ratio	Conical Apex Angle	Hemispherical Radius	Flat Diameter	Side to Pressure (Convex or Concave)
(a) Top, bottom, ends								
(b) Channel								

If removable, bolts used (a) .... (b) .... (c) .... Other fastening .... (Describe or attach sketch)

14. Constructed for specified operating pressure[2] .... psi at max. temp. .... °F Charpy Impact .... ft-lb at temp. of .... °F

Items below to be completed for all vessels where applicable

15. Safety Valve Outlets: Number .... Size .... Location ....

16. Nozzles:

Purpose (Inlet, Outlet, Drain)	Number	Diam. or Size	Type	Material	Thickness	Reinforcement Material	How Attached

17. Inspection Openings: Manholes, No. .... Size .... Location ....

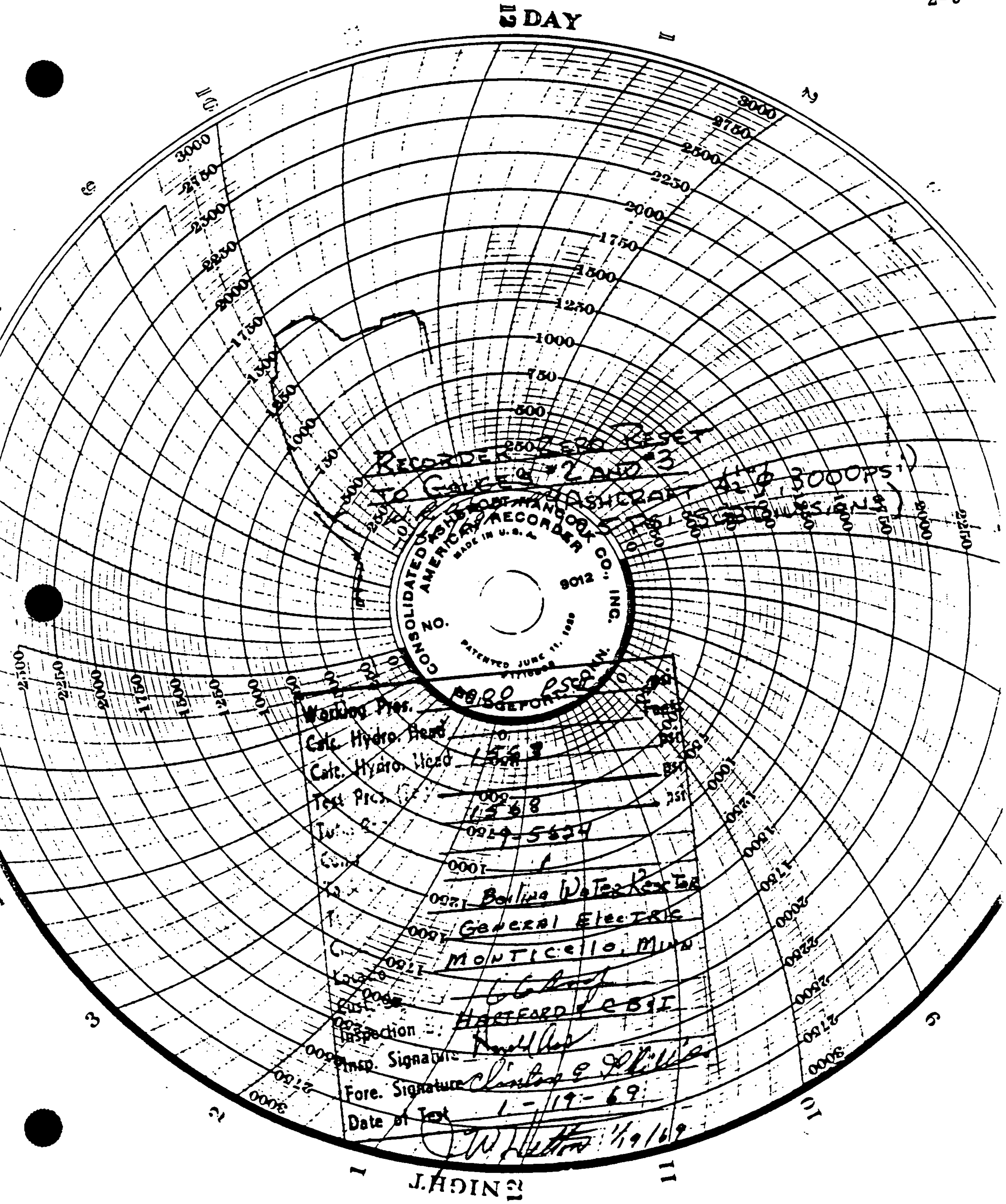
Handholes, No. .... Size .... Location ....

Threaded, No. .... Size .... Location ....

18. Supports: Skirt .... (Yes or No) Lugs .... (Number) Legs .... (Number) Other .... (Describe) Attached .... (Where & How)

[1] If Postweld Heat-Treated.

[2] List other internal or external pressure with coincident temperature when applicable.


DAY
NIGHT
CONSOLIDATED ASHCROFT HANCOCK CO., INC.
AMERICAN RECORDER
MADE IN U.S.A.
NO.
9012
BRIDGEPORT, CONN.
Working Pres.
Calc. Hydro. Head
Test Pres.
1568
Boiling Water Reactor
General Electric
Monticello, Minn
Hartford & CBI
Inspection
Insp. Signature
Fore. Signature
Date of Test
1-19-69

SUBJECT - ASME Code, Section III Hydrostatic Test

PROJECT - Monticello Nuclear Reactor 9-5624

Type of Vessel - Boiling Water Nuclear Reactor
Vessel Material - A533 Class I Grade Firebox Quality
Vessel Height - 46'-0" ± 1 1/2" T.L.
Vessel Diameter - 17'-2 ∓ 3/8" Base Metal I.D.
Shell Thickness - 5 1/16" Min.
Design Pressure - 1250 psig at bottom of vessel
Design Temperature - 575°F
Hydrostatic Test Pressure - 1563 psig at bottom of vessel
Design Code - ASME Code, Section III, 1965 edition including Summer 1966 addenda, and the following additions or exceptions:

A.--Details governed by analysis only.

1. Main closure flange configuration.
2. Configuration of the skirt attachment knuckle.

B.--Application of Code Revisions not covered by the Summer 1966 addenda.

1. ASME SA533 plate material Summer 1967 addenda.
2. Inconel material per Summer 1967 addenda
3. Main closure flange material per code case 1332-3.
4. Studs and nuts material for main closure flanges per code case 1335-2.
5. Main closure flange stud shank transition radius per code case 1366.
6. Bearing stresses for stabilizer brackets per Winter 1967 addenda.
7. Coefficients of Thermal Expansion per Winter 1967 addenda.
8. Magnetic particle and liquid penetrant examination per Winter 1966 addenda.

Design Specifications - Certified G.E. Specification No. 21A1112, Rev. 5
Vessel Manufactured by - Chicago Bridge & Iron Company
Vessel Manufactured for - General Electric Company

The above vessel was hydrostatically tested according to the rules of ASME Code, Section III, Paragraph N-712. No detectable defects were found. The vessel was built and inspected according to the rules of ASME Code Section III (see above), and complies with the manufacturer's drawings. The vessel is completed except for the certification of the stress report and completion of the final ASME Code, Section III inspections.

Signed Harold Bye
Hartford Inspector

DATE 1-19-69

PROJECT Monticello Nuclear Reactor 9-5624

SUBJECT - LEAKAGE TEST

The leakage test of the gaskets in the vessel head closure flanges was performed as specified in procedure DHT-1, Rev. ~~2~~ 3. The test was performed in conjuction with the hydrostatic test at design pressure per customer's specification, 21A1112, Rev. ~~4~~ 5, Paragraph 10.8.2.

No significant leakage was found in the inner or outer gaskets of the vessel closure flanges.

Signed

William R. Wagner 1/30/69 for CB&I
Quality Control Inspector

[illegible] 1/30/69 for G.E.

DATE

CHICAGO BRIDGE & IRON COMPANY
P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: MARCH 11, 1969

REFERENCE: BOILING WATER NUCLEAR REACTOR VESSEL
17.167' ID x 63.167 INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
GENERAL ELECTRIC CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: HYDROSTATIC TESTING CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that the above referenced vessel was hydrostatically tested in accordance with the ASME Code, Section III, 1965 Edition, with addenda through Summer 1966 and General Electric Co. Specification 21A1112, Rev. 5, Paragraph 10.8 and also approved CB&I procedures CHT-1 Revision I and DHT I Revision 3. (included in Monticello Project Manual Volume II). Furthermore, no significant leakage was detected in the inner or outer gaskets of the vessel and closure head flanges. See attachments.

CHICAGO BRIDGE & IRON COMPANY

E.E. Varnum

E.E. VARNUM
NUCLEAR QUALITY ASSURANCE MANAGER

CHICAGO BRIDGE & IRON COMPANY
P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: March 11, 1969

REFERENCE: BOILING WATER NUCLEAR REACTOR VESSEL
17.167' x 63.167' INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
GE CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: RADIOGRAPHIC TESTING CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that radiographic examinations for the above referenced vessel were performed in accordance with the ASME Code, Section III, 1965 Edition, with Addenda through Summer 1966 and General Electric Co. Specification 21A1112, Revision 5, Paragraph 10.7 and also approved CB&I Co. and/or suppliers Procedures RTP-1 Rev.2, and advanced products radiographic procedure of finished welds, Rev. 2 (above procedures included in Monticello Project Manual Volume II).

CHICAGO BRIDGE & IRON COMPANY

E.E. Varnum

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NUCLEAR QUALITY ASSURANCE MANAGER

CHICAGO BRIDGE & IRON COMPANY
P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

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17.167' x 63.167' INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO,MINNESOTA
G.E. Co. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: ULTRASONIC TESTING CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that ultrasonic examinations for the above referenced vessel were performed in accordance with the ASME Code, Section III, 1965 Edition, with Addenda through Summer 1966, and General Electric Co. Specification 21A1112 Rev. 5, Paragraphs 10.5 and 10.6, and also approved CB&I Co. and/or suppliers procedures HT-101 Rev. 2, LE-2 Rev. 0, QCP-89 w/addendum Rev.0, TT-2 Rev.1, UTP-1 Rev.3, UTP-2 Rev.1 (same as 9Q-63 Rev.1), UTP-3 Rev.0, UTP-4 Rev.0, UTP-5 Rev.1, UTP-6 Rev.1, UTP-7 Rev.1, UTP-8 Rev.0, UTP-10 Rev.0 and UT-718777 Rev. 0 (above procedures included in Monticello Project Manual Volume II).

CHICAGO BRIDGE & IRON COMPANY

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CHICAGO BRIDGE & IRON COMPANY
P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: March 11, 1969

REFERENCE: BOILING WATER NUCLEAR REACTOR VESSEL
17.167' x 63.167' INS.HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINNESOTA
GE CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: LIQUID PENETRANT TESTING CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that liquid penetrant examinations for the above referenced vessel were performed in accordance with the ASME Code, Section III, 1965 Edition, with Addenda through Summer 1966, and General Electric Co. Specification 21A1112 Rev. 5, Paragraph 10.6, and also approved CB&I Co. and/or suppliers procedures LE-4 Rev.0, PTP-1 Rev.3, PT-71877 Rev.0, advanced products liquid penetrant procedure Rev.1 and TT-4 Rev.1 (above procedures included in Monticello Project Manual Volume II).

CHICAGO BRIDGE & IRON COMPANY

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CHICAGO BRIDGE & IRON COMPANY
P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: March 11, 1969

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17.167' x 63.167' INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
G.E. CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: MAGNETIC PARTICLE CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that magnetic particle examinations for the above referenced vessel were performed in accordance with the ASME Code, Section III, 1965 Edition, with Addenda through Summer 1966, and General Electric Co. Specification 21A1112 Rev. 5, Paragraph 10.6 and also approved CB&I Co. and/or supplier's procedures LE-3 Rev. 0, MTP-1 Rev. 4, MTP-2 Rev. 1 (also known as Ladish 143-M), NDT-M-1 Rev. 0 and TT-3 Rev. 1 (above procedures included in Monticello Project Manual Volume II).

CHICAGO BRIDGE & IRON COMPANY

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CHICAGO BRIDGE & IRON COMPANY

P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: March 11, 1969

REFERENCE: BOILING WATER NUCLEAR REACTOR VESSEL
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MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
G.E. CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: FINAL CLEANING CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that the final cleaning of the above referenced vessel was performed in accordance with the ASME Code, Section III, 1965 Edition, with Addenda through Summer 1966, and General Electric Co. Specification 21A1112 Rev.5 Paragraph 10.8 and also approved CB&I Co. Procedure CP-4 Rev.1 (above procedure included in Monticello Project Manual Volume II).

CHICAGO BRIDGE & IRON COMPANY

E.E. Varnum

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NUCLEAR QUALITY ASSURANCE MANAGER

CHICAGO BRIDGE & IRON COMPANY
P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: March 11, 1969

REFERENCE: BOILING WATER NUCLEAR REACTOR VESSEL
17.167' x 63.167' INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
G.E. CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: WELDING CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that welding of the above referenced vessel was performed in accordance with the ASME Code, Section III, 1965 Edition, with Addenda through Summer 1966, and General Electric Co. Specification 21A1112 Rev. 5, Paragraph 9.3 and also approved CB&I Co. procedures

WPS-1	Rev. 2	WPS-18	Rev. 4	WPS-35	Rev. 1
WPS-2	Rev. 2	WPS-19	Rev. 3	WPS-36	Rev. 0
WPS-3	Rev. 0	WPS-20	Rev. 0	WPS-37	Rev. 1
WPS-4	Rev. 2	WPS-21	Rev. 1	WPS-38	Rev. 1
WPS-5	Rev. 0	WPS-22	Rev. 1	WPS-39	Rev. 0
WPS-6	Rev. 2	WPS-23	Rev. 1	WPS-40	Rev. 1
WPS-7	Rev. 2	WPS-24	Rev. 4	WPS-41	Rev. 0
WPS-8	Rev. 0	WPS-25	Rev. 0	WPS-42	Rev. 1
WPS-9	Rev. 0	WPS-26	Rev. 0	WPS-43	Rev. 0
WPS-10	Rev. 0	WPS-27	Rev. 2	WPS-44	Rev. 3
WPS-11	Rev. 0	WPS-28	Rev. 5	WPS-45	Rev. 0
WPS-12	Rev. 2	WPS-29	Rev. 1	WPS-46	Rev. 0
WPS-13	Rev. 3	WPS-30	Rev. 2	WPS-47	Rev. 0
WPS-14	Rev. 2	WPS-31	Rev. 1	WPS-48	Rev. 0
WPS-15	Rev. 0	WPS-32	Rev. 1	WPS-49	Rev. 2
WPS-16	Rev. 2	WPS-33	Rev. 0	WPS-50	Rev. 2
WPS-17	Rev. 1	WPS-34	Rev. 1	WPS-51	Rev. 0

CHICAGO BRIDGE & IRON COMPANY

SUBJECT: WELDING CERTIFICATION

WPS-52	Rev. 1	WPS-64	Rev. 0
WPS-53	Rev. 0	WPS-66	Rev. 0
WPS-55	Rev. 0	WPS-68	Rev. 1
WPS-56	Rev. 0	WPS-69	Rev. 0
WPS-58	Rev. 0	WPS-73	Rev. 1
WPS-59	Rev. 0	WPS-74	Rev. 1
WPS-60	Rev. 0	WPS-75	Rev. 0
WPS-63	Rev. 0	WPS-77	Rev. 0

(above procedures included in Monticello Project Manual Volume II).

CHICAGO BRIDGE & IRON COMPANY

E. E. Varnum

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NUCLEAR QUALITY ASSURANCE MANAGER

CHICAGO BRIDGE & IRON COMPANY

P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

DATE: March 11, 1969

REFERENCE: BOILING WATER NUCLEAR REACTOR VESSEL
17.167' x 63.167' INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
G.E. CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: WELD REPAIR CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that any weld repair done on the above referenced vessel was performed in accordance with the ASME Code, Section III, 1965 Edition, with Addenda through Summer 1966, and General Electric Co. Specification 21A1112 Rev. 5, Paragraphs 9.3 and 9.4 and also approved CB&I Co. procedures GRP-1 Rev. 0, GRP-2 Rev. 1, GRP-3 Rev. 3, GRP-4 Rev. 0, GRP-5 Rev. 3, GRP-6 Rev. 0 and GRP-7 Rev. 0 (above procedures included in Monticello Project Manual Volume II).

CHICAGO BRIDGE & IRON COMPANY

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NUCLEAR QUALITY ASSURANCE MANAGER

CHICAGO BRIDGE & IRON COMPANY

P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: March 11, 1969

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17.167' x 63.167' INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
G.E. CO. P. O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: HEAT TREATMENT CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that the heat treatment performed on the above referenced vessel was done in accordance with the ASME Code, Section III, 1965 Edition, with Addenda through Summer, 1966, General Electric Company Specification 21A1112 Revision 5, Paragraphs 8.0 and 9.0 and approved CB&I Company Procedures HTP-1 Revision 1, HTP-2 Revision 1, HTP-3 Revision 1, HTP-4 Revision 1 and HTP-5 Revision 0. Performance of heat treatment of material by suppliers is certified in the mill test reports. This work was performed in accordance with one or more of the following procedures: HLA-1 Revision 1, HT-718777 Revision 0, LE-1 Addendum 1 Revision 0, LE-5 Revision 3, LE-6 Revision 0, LE-7 Revision 1, LE-8 Revision 1, LE-9 Revision 1, LE-12 Revision 0, LS-1 Revision 2, LS-2 Revision 0, TS-1 Revision 0, TS-2 Revision 0, TS-3 Revision 0, TT-1 Revision 1, TT-5 Revision 1, TT-6 Revision 1, CA-1 Revision 1 and CA-2 Revision 1 (all of above CB&I Company and suppliers procedures included in Monticello Project Manual Volume II).

CHICAGO BRIDGE & IRON COMPANY

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CHICAGO BRIDGE & IRON COMPANY
P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: March 11, 1969

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17.167' ID x 63.167' INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
GENERAL ELECTRIC CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: WELD ROD AND WIRE CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that all weld rod and wire used in the fabrication of the above referenced vessel was within the acceptable limits of the ASME Code, Section III, 1965 Edition, with Addenda through Summer 1966, and General Electric Co. Specification 21A1115 Rev. 5, Paragraph 8.15 and also approved Chicago Bridge & Iron Company procedures which are included in Monticello Project Manual Volume II.

The types of weld rod and wire used in this contract were as follows:

SA316-E-8018 G

SA233-E-7018

SA298-E-308-15

SA371-ER-309ELC

SA298-E-309-15

SA371-ER-308L

SA298-E-308L-15

SA298-E-308L

SA298-E-308

CHICAGO BRIDGE & IRON COMPANY

SUBJECT: WELD ROD AND WIRE CERTIFICATION

SA298-E-309

SB295-Inco 182

SB304-Inco 82

SB304-ERNiCr-3

SB295-ENiCrFe-3

Linde 40 w/1% Ni or equal.

CHICAGO BRIDGE & IRON COMPANY

E. E. Varnum

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NUCLEAR QUALITY ASSURANCE MANAGER

CHICAGO BRIDGE & IRON COMPANY
P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: MARCH 11, 1969

REFERENCE: BOILING WATER NUCLEAR REACTOR VESSEL
17.167' ID x 63.167" INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
GENERAL ELECTRIC CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: CLADDING CARBON CONTENT CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that the cladding has been accepted by General Electric Company as meeting the intent of Specification 21A1112 Revision 5, Paragraph 8.10, and of the contract. Furthermore, the carbon content of the cladding does not exceed 0.08% as specified in the above General Electric Company Specification.

CHICAGO BRIDGE & IRON COMPANY

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NUCLEAR QUALITY ASSURANCE MANAGER

CHICAGO BRIDGE & IRON COMPANY
P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: March 11, 1969

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17.167' ID x 63.167' INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
GENERAL ELECTRIC CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: WELDER QUALIFICATION CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that all welder qualifications for both shop and field fabrication of the above referenced vessel were performed in accordance with the ASME Code, Sections III and IX, 1965 Edition, with Addenda through Summer 1966, and General Electric Specification 21A1112 Rev. 5, Paragraph 9.0. Copies of these qualification records are on file with Chicago Bridge & Iron Company and will be furnished to General Electric Co. upon written request.

CHICAGO BRIDGE & IRON COMPANY

E. E. Varnum

E. E. VARNUM
NUCLEAR QUALITY ASSURANCE MANAGER

CHICAGO BRIDGE & IRON COMPANY
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901 947-3111

DATE: March 11, 1969

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MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
GENERAL ELECTRIC CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: PARKERIZING CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that the Parkerizing performed on equipment supplied with the above referenced vessel was done in accordance with Federal Specification TT-C-490 dated March 30, 1961, titled: "Cleaning Methods and Pretreatment of Ferrous Surfaces for Organic Coatings", this procedure was approved by General Electric Co. for use on this contract, November 28, 1967. Process was performed for Chicago Bridge & Iron Co. by Hayes Aircraft Corporation, Birmingham, Alabama.

CHICAGO BRIDGE & IRON COMPANY

E. E. Varnum

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NUCLEAR QUALITY ASSURANCE MANAGER

CHICAGO BRIDGE & IRON COMPANY
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MONTICELLO PROJECT, MONTICELLO, MINN.
GENERAL ELECTRIC CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: MATERIAL CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that the material in the above referenced vessel is in accordance with the ASME Code, Section III, 1965 Edition, with Addenda through Summer 1966, and General Electric Co. Specification 21A1112 Rev. 5, Paragraph 8.0 and also approved Chicago Bridge & Iron Company procedures MS-1 Rev. 0, MS-2 Rev. 1, MS-3 Rev. 3, MS-4 Rev. 3, MS-5 Rev. 1, MS-6 Rev. 1. MS-7 Rev. 2, MS-8 Rev. 0, MS-9 Rev. 0, MS-10 Rev. 0, MS-11 Rev. 2, MS-12 Rev. 0, MS-13 Rev. 2, MS-14 Rev. 0, MS-15 Rev. 2, MS-16 Rev. 1, MS-17 Rev. 1 and MS-MISC.-1 Rev. 1 (above procedures included in Monticello Project Manual Volume I).

CHICAGO BRIDGE & IRON COMPANY

E. E. Varnum

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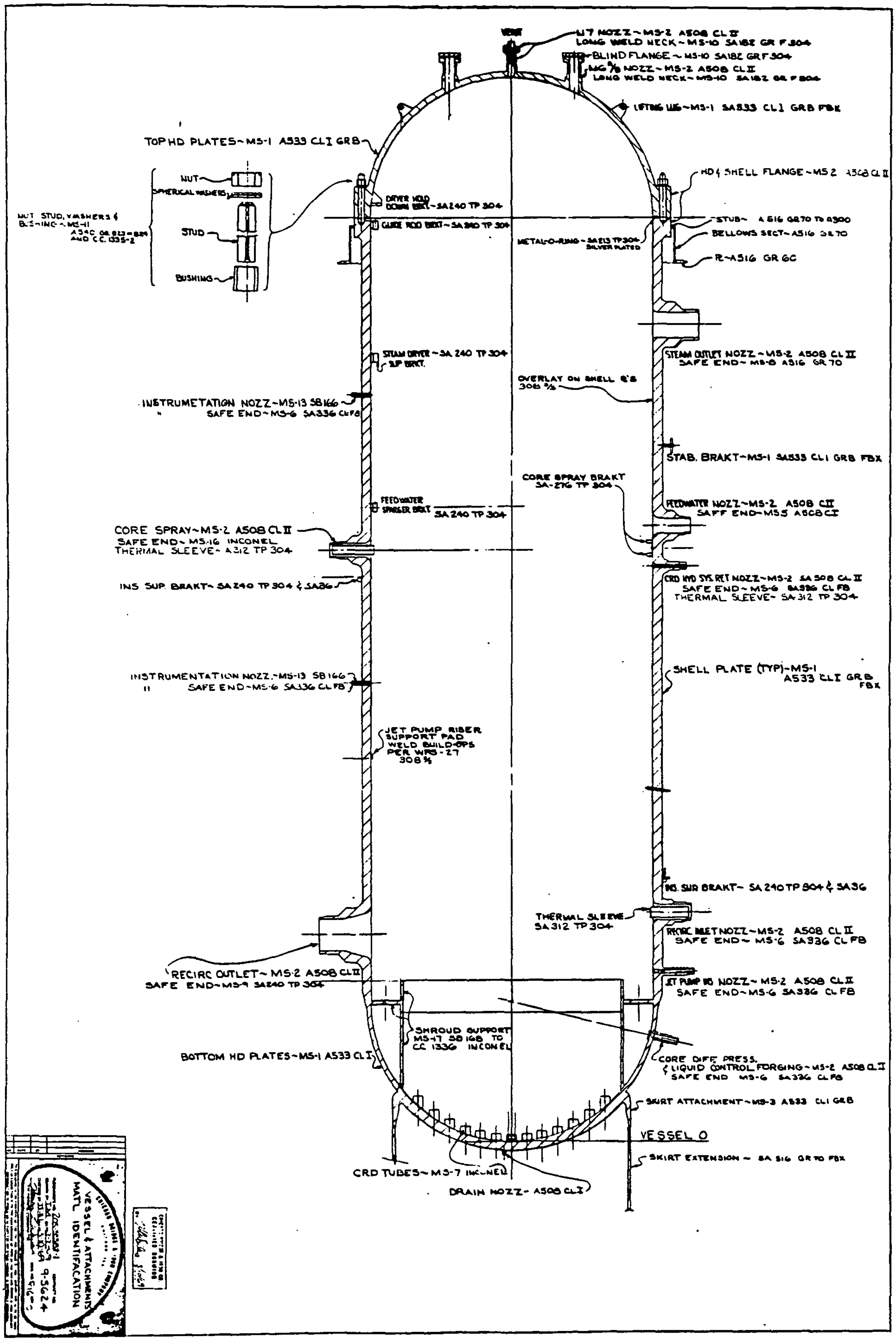
NUCLEAR QUALITY ASSURANCE MANAGER


VENT
N7 NOZZ~MS-2 A508 CL II
LONG WELD NECK~MS-10 SA182 GR F304
BLIND FLANGE~MS-10 SA182 GR F304
N6 A/B NOZZ~MS-2 A508 CL II
LONG WELD NECK~MS-10 SA182 GR F304
LIFTING LUG~MS-1 SA533 CL1 GRB FBX
TOP HD PLATES~MS-1 A533 CL I GRB
NUT
SPHERICAL WASHERS
STUD
BUSHING
NUT STUD, WASHERS & BUSHING~MS-11 A540 GR B23-B24 AND C.C. 1335-2
DRYER HOLD DOWN BRKT~SA240 TP 304
GUIDE ROD BRKT~SA240 TP 304
HD & SHELL FLANGE~MS 2 A508 CL II
STUD~ A 516 GR70 To A300
BELLOWS SECT~A516 GR70
METAL-O-RING~SA213 TP304 SILVER PLATED
R~A516 GR 6C
STEAM DRYER~SA 240 TP 304 SUP BRKT.
STEAM OUTLET NOZZ~MS-2 A508 CL II
SAFE END~MS-8 A516 GR 70
OVERLAY ON SHELL ID'S 308 S/S
INSTRUMETATION NOZZ~MS-13 SB166
SAFE END~MS-6 SA336 CL F8
STAB. BRAKT~MS-1 SA533 CL I GRB FBX
CORE SPRAY BRAKT SA-276 TP 304
FEEDWATER SPARGER BRKT SA 240 TP 304
FEEDWATER NOZZ~MS-2 A508 CL II
SAFE END~MS5 A508 CL I
CORE SPRAY~MS-2 A508 CL II
SAFE END~MS-16 INCONEL
THERMAL SLEEVE~A312 TP 304
INS SUP BRAKT~SA240 TP 304 & SA36
CRD HYD SYS RET NOZZ~MS-2 SA 508 CL II
SAFE END~MS-6 SA336 CL F8
THERMAL SLEEVE~SA 312 TP 304
SHELL PLATE (TYP)~MS-1 A533 CL I GRB FBX
INSTRUMENTATION NOZZ.~MS-13 SB166
SAFE END~MS-6 SA336 CL F8
JET PUMP RISER SUPPORT PAD WELD BUILD-UPS PER WPS-27 308 S/S
INS. SUP BRAKT~ SA 240 TP 304 & SA36
THERMAL SLEEVE SA 312 TP 304
RECIRC INLET NOZZ~MS-2 A508 CL II
SAFE END~ MS-6 SA336 CL F8
RECIRC OUTLET~MS-2 A508 CL II
SAFE END~MS-9 SA240 TP 304
JET PUMP INST NOZZ~MS-2 A508 CL II
SAFE END~MS-6 SA336 CL F8
SHROUD SUPPORT MS-17 SB168 TO CC 1336 INCONEL
BOTTOM HD PLATES~MS-1 A533 CL I
CORE DIFF PRESS. & LIQUID CONTROL FORGING~MS-2 A508 CL II
SAFE END MS-6 SA336 CL F8
SKIRT ATTACHMENT~MS-3 A533 CL I GRB
VESSEL 0
SKIRT EXTENSION~SA 516 GR 70 FBX
CRD TUBES~MS-7 INCONEL
DRAIN NOZZ~A508 CL I
VESSEL & ATTACHMENTS
MATL IDENTIFACATION
9-3624

CHICAGO BRIDGE & IRON COMPANY

P. O. BOX 13308, MEMPHIS, TENNESSEE 38113

901 947-3111

DATE: March 11, 1969

REFERENCE: BOILING WATER NUCLEAR REACTOR VESSEL
17.167' ID x 63.167' INS. HDS.
MANUFACTURER'S SERIAL NO. B-4697
MONTICELLO PROJECT, MONTICELLO, MINN.
GENERAL ELECTRIC CO. P.O. 205-55582-I
CB&I CONTRACT 9-5624

SUBJECT: FABRICATION TEST PROGRAM CERTIFICATION

TO WHOM IT MAY CONCERN:

This is to certify that the fabrication test program was performed for the above referenced vessel in accordance with Attachment "B" Rev. 3 of General Electric Co. Specification 21A1112 Rev. 5, Paragraph 2.0 titled: "Fabrication Test Program" and using specimens cut from plate of same heat as plate used in the vessel. These specimens were cold formed to CFP-1 Rev. 0 which corresponded to the cold forming performed on the plates of the Reactor Vessel.

Paragraph 2.2.3 of Attachment "B" was complied with by submitting "For Information Only" the test reports for 80% T tensile test on Chicago Bridge & Iron Company letter BBE-198 dated 8/9/68. The above test reports were compiled by the University of Illinois. Chicago Bridge & Iron Company took exception to Paragraph 2.2.3.2 of Attachment "B" and subsequently, agreement was reached with General Electric Co. during the meetings held in San Jose, California, August 22 through August 25, 1966, in the following manner:

Page 10 Item G-1

> "The 80% T dia. test specimens from as formed plate may come from rolled plate with girth (category B) seam so that separate welded on grips are not necessary. This interprets differently the plate as regards Paragraph 2.2.3.2 of the GE Specification, but Paul Herbert and Bud Vancott (both were in the meeting when this was discussed) agreed that this was acceptable."

CHICAGO BRIDGE & IRON COMPANY

SUBJECT: FABRICATION TEST PROGRAM CERTIFICATION

Attachments:

1. CB&I Drawing T-4 Rev. 4, Results of Charpy V-notch impact tests as per Paragraph 2.2.4 of Attachment B.
2. CB&I Drawing T-5 Rev. 3, Results of tensile tests as per Paragraph 2.2.2 of Attachment B.

CHICAGO BRIDGE & IRON COMPANY

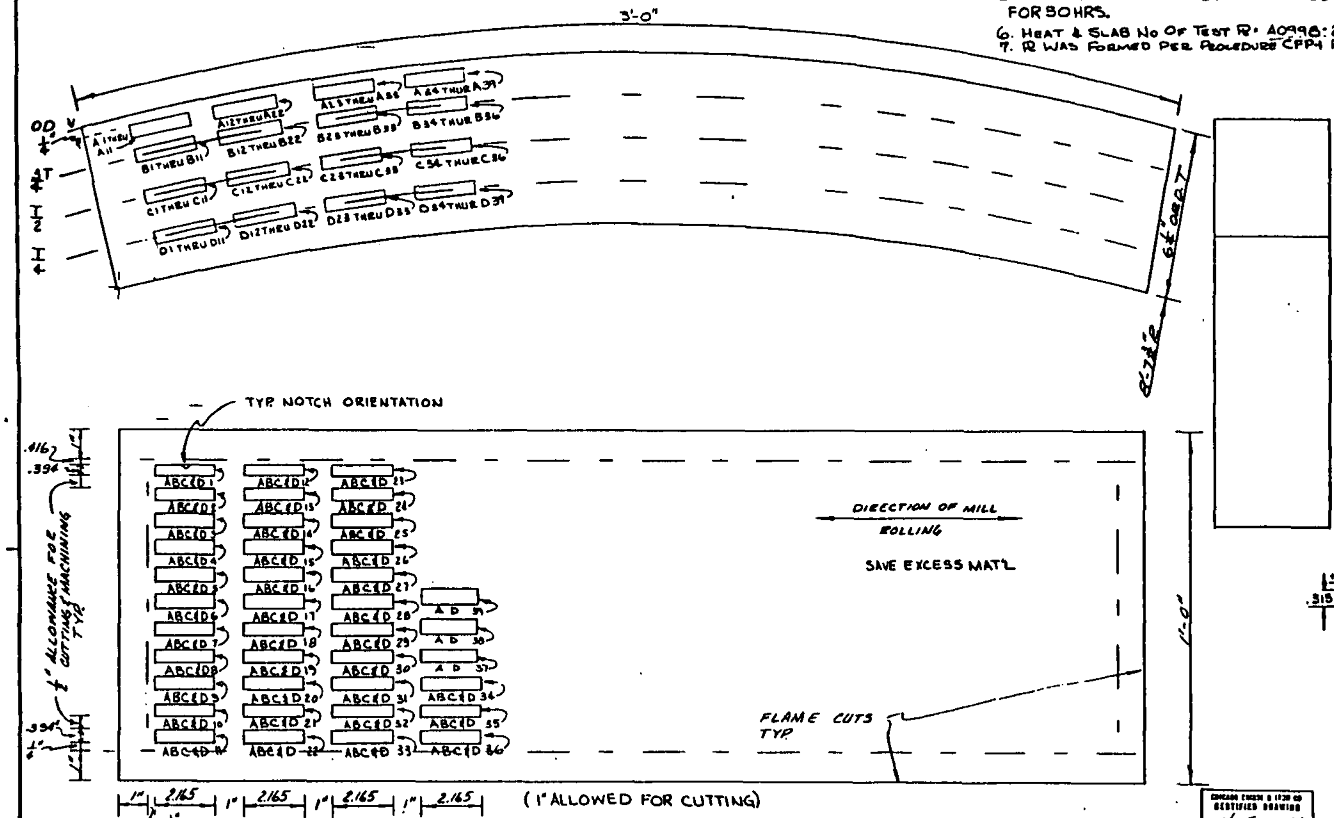
E. E. Varnum

E. E. VARNUM
NUCLEAR QUALITY ASSURANCE MANAGER

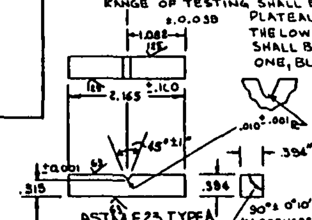
SHOP PC	MARK	ASSM PC	DESCRIPTION			SPEC.
	ABC(D)1 THRU ABC(D)36	144	CHARPY Vee NOTCH TEST SPECIMENS AS INDICATED			A533 CL.1 GR.B FBX MS-1

CUT ABOVE MATERIAL FROM # 3 R BILLED ON DWG. T3

NOTES: (CONT.)
5. PWHT @ 1150°F PLUS 25°F OR MINUS 50°F FOR 50 HRS.
6. HEAT & SLAB No OF TEST R: A0998:2.
7. R WAS FORMED PER PROCEDURE CFP4 RO.



NOTES:
1. ALL SPECIMENS SHALL BE 6" FROM ANY QUENCHED EDGE.
2. FINAL CUTTING SHALL BE DONE BY MACHINING.
3. SHOP MAKE AND TEST CHARPY V-NOTCH IMPACT SPECIMEN (ASTM E23, TYPE A) ENTIRELY FROM BASE MATERIAL TO ESTABLISH CURVES FOR DETERMINING THE 30 FT.-LB. TRANSITION TEMPERATURE AT THE O.D., 1/4 T, 1/2 T, AND 3/4 T THICKNESS LEVELS OF THE PLATE MATERIAL. THE ENERGY DATA, FRACTURE APPEARANCE DATA AND LATERAL EXPANSION DATA FOR EACH INDIVIDUAL SPECIMEN SHALL BE REPORTED. THERE SHALL BE AT LEAST SIX POINTS REPORTED WITHIN THE 20 TO 40 FT-LB. RANGE, AND AT LEAST THREE TESTING TEMPERATURES REPRESENTED WITHIN THE RANGE. IN ADDITION TO THE ABOVE THE IMPACT TRANSITION CURVES SHALL CONFORM TO NOTE 4.
4. SHOP MAKE IMPACT TRANSITION CURVE REPRESENTING BREAKING ENERGY VS. TEMPERATURE FROM AT LEAST TWELVE TYPE A CHARPY-V SPECIMEN, TESTED IN ACCORDANCE WITH ASTM A370, EXCEPT EACH SPECIMEN TESTED AT A DIFFERENT TEMPERATURE. THE TEMPERATURE RANGE OF TESTING SHALL ESTABLISH THE UPPER PLATEAU, TRANSITION REGION, AND THE LOWER PLATEAU. EACH PLATEAU SHALL BE DETERMINED BY AT LEAST ONE, BUT NOT MORE THAN TWO POINTS. THE REMAINING SPECIMENS SHALL BE USED TO DEVELOP THE TRANSITION REGION. THE LOWER PLATEAU NEED NOT BE DEVELOPED IF IT OCCURES BELOW -80°F.



ASTM E23 TYPE A

MARK	TEMP °F	ENERGY ABS FT-LB	LATERAL EXPANSION MILS	FRACTURE APPEARANCE DATA	MARK	TEMP °F	ENERGY ABS FT-LB	LATERAL EXPANSION MILS	FRACTURE APPEARANCE DATA
D1	0	54.5	46	35	D19	-20	57	48	35
D2	-20	25.5	21	15	D20	-18	20	18	2
D3	-10	59	49	50	D21	-18	28.5	25	8
D4	-15	51.5	42	40	D22	+5	45	39	25
D5	-30	18	16	10	D23	+10	35	31	20
D6	-25	11.5	11	2	D24	+15	42.5	37	20
D7	-18	25.5	23	10	D25	+25	81	66	55
D8	-5	43	37	20	D26	-80	24	20	2
D9	-5	43	34	20	D27	+150	117	81	100
D10	-12	43	36	10	D28	-80	7	6	0
D11	-12	48	40	12	D29	+140	103	81	85
D12	-23	23	20	5	D30	-70	4.5	2	0
D13	-23	43.5	35	12	D31	+130	126	88	100
D14	-18	42	36	15	D32	-60	17.5	13	2
D15	-20	34	31	10	D33	+120	101.5	79	85
D16	-15	48.5	37	15	D34	-50	35.5	43	20
D17	-25	44.5	37	15	D35	+80	97.5	75	75
D18	-25	8.5	9	2	D36	-100	7	4	0

MARK	TEMP °F	ENERGY ABS FT-LB	LATERAL EXPANSION MILS	FRACTURE APPEARANCE DATA	MARK	TEMP °F	ENERGY ABS FT-LB	LATERAL EXPANSION MILS	FRACTURE APPEARANCE DATA	MARK	TEMP °F	ENERGY ABS FT-LB	LATERAL EXPANSION MILS	FRACTURE APPEARANCE DATA
A1	0	56	48	25	A19	+10	60.5	51	35	B1	0	21	21	5
A2	-20	60.5	51	20	A20	+15	62	52	30	B2	-20	41.5	32	15
A3	-30	33.5	28	10	A21	+25	67	53	35	B3	-10	17.5	16	2
A4	-40	10.5	11	2	A22	+70	76.5	60	60	B4	+10	54	46	35
A5	-35	13.5	12	5	A23	+60	72.5	73	65	B5	-15	35	31	15
A6	-25	10	11	2	A24	+50	90.5	70	65	B6	-5	14.5	18	15
A7	-	-	-	-	A25	+75	103	76	75	B7	+5	49	43	30
A8	-28	40	32	12	A26	+90	102.5	79	75	B8	-8	24	20	8
A9	-28	13	15	5	A27	-45	11	10	5	B9	-8	11.5	13	5
A10	-12	32.5	29	10	A28	+110	122	88	100	B10	-12	17	16	2
A11	-12	41	34	12	A29	-50	61	47	20	B11	-12	23	20	5
A12	-15	26	24	5	A30	+100	123	81	90	B12	-10	44	36	20
A13	-15	11	17	2	A31	-50	9	14	2	B13	-10	43	35	20
A14	-18	41.5	34	12	A32	+110	125	75	100	B14	-18	28.5	24	10
A15	-18	24.5	23	5	A33	-60	27	20	5	B15	-18	14	35	20
A16	-20	30.5	25	8	A34	+130	120	87	100	B16	-5	23	20	5
A17	-20	28.5	25	8	A35	-70	17	15	2	B17	-5	28.5	24	8
A18	+6	67	54	35	A36	-80	10	8	0	B18	+15	60.5	52	30
A37	-120	6.5	4	0	A3[illegible]	+260	133	90	100					
A38	+180	126	85	100										

MARK	TEMP °F	ENERGY ABS FT-LB	LATERAL EXPANSION MILS	FRACTURE APPEARANCE DATA	MARK	TEMP °F	ENERGY ABS FT-LB	LATERAL EXPANSION MILS	FRACTURE APPEARANCE DATA	MARK	TEMP °F	ENERGY ABS FT-LB	LATERAL EXPANSION MILS	FRACTURE APPEARANCE DATA
B19	-20	53.5	47	30	C1	0	55.5	47	30	C19	+25	61.5	56	40
B20	+25	61	47	30	C2	-20	12	15	10	C20	+35	73.5	65	55
B21	+35	70.5	51	35	C3	-10	27	26	15	C21	-80	5.5	4	0
B22	-80	9	10	0	C4	+10	72	59	55	C22	+150	135.5	88	100
B23	+150	118.5	84	100	C5	0	26.5	26	15	C23	+140	115.5	86	100
B24	+140	122.5	77	100	C6	-5	54	46	30	C24	-70	17	14	2
B25	-70	30	27	5	C7	-3	46.5	40	25	C25	+130	128.5	89	100
B26	+130	104	77	85	C8	-8	48	43	25	C26	-60	16.5	14	2
B27	-60	17.5	16	2	C9	-8	58.5	50	35	C27	+120	135	85	100
B28	+120	111.5	82	85	C10	-12	20.5	17	5	C28	-50	9	7	0
B29	-50	10	9	0	C11	-12	37	22	10	C29	+100	112.5	87	85
B30	+100	112	85	90	C12	-10	36.5	32	12	C30	-30	45.5	36	10
B31	-30	43.5	38	20	C13	-10	56	47	25	C31	+80	120	75	85
B32	+80	91	73	70	C14	-15	54	45	25	C32	-100	5.5	5	0
B33	-100	11	12	0	C15	-18	38.5	33	10	C33	+60	105	79	65
B34	+180	127.5	91	100	C16	-18	23	21	5	C34	+180	101	75	100
B35	+180	120.5	88	100	C17	+15	64.5	55	30	C35	+180	97.5	61	100
B36	+200	119	87	100	C18	+20	79	64	55	C36	+200	77	73	100
					D37	-50	90	61	55	D3[illegible]	+200	124	96	[illegible]
					D38	+180	114.5	81	100					

CHICAGO BRIDGE & IRON CO. CERTIFIED DRAWING BY [signature]

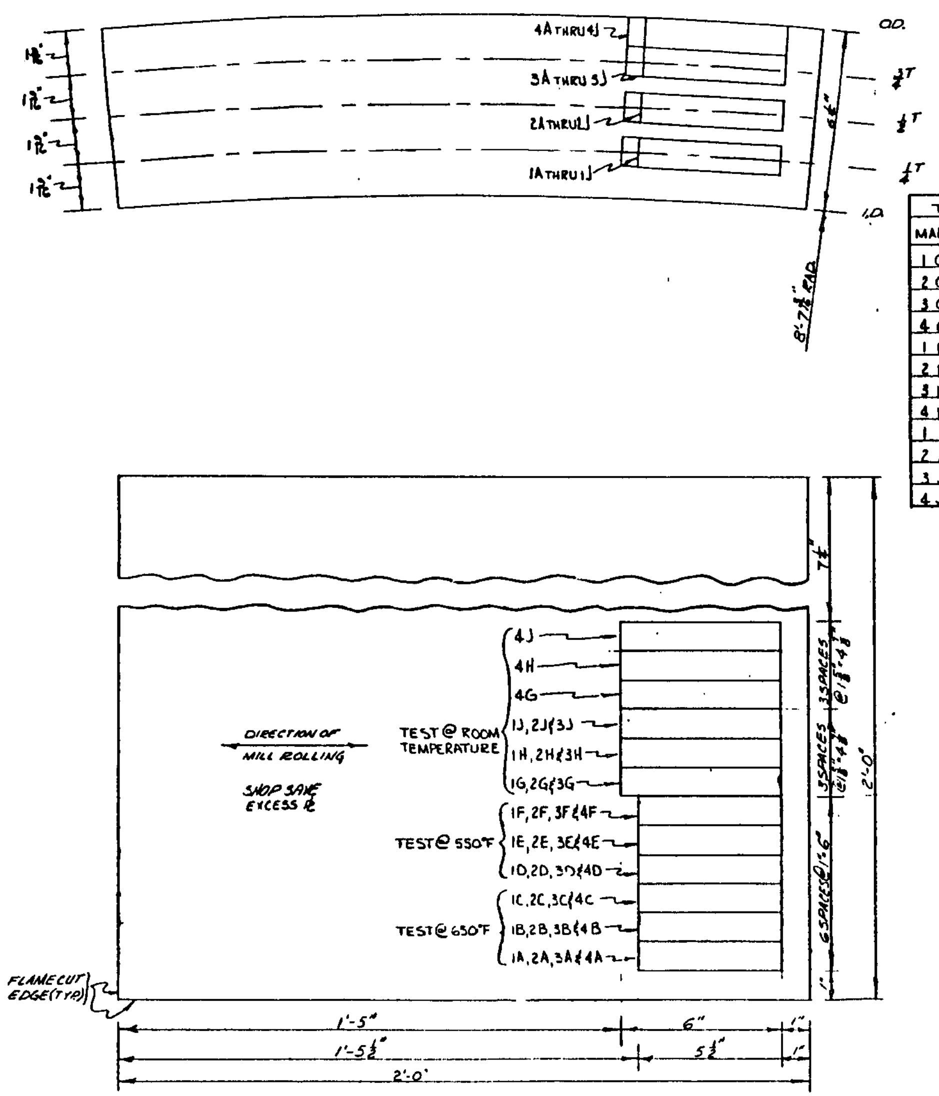
Reviewed by GE/APED and released 6-[illegible]

CHICAGO BRIDGE & IRON COMPANY
"PAR 2.2A"
FABRICATION TEST
CHARPY VEE NOTCH SPECIMEN
for NUCLEAR REACTOR for GENERAL ELECTRIC Co. for NORTHERN STATES POWER Co. MONTICELLO, MINN.
PURCHASER'S NO. 205-55581-1
CONTRACT NO. 9-5624
DRAWN BY C.P.R.
CHECKED BY
R.L. WAIL[illegible]
DWG NO. T4 REV 4

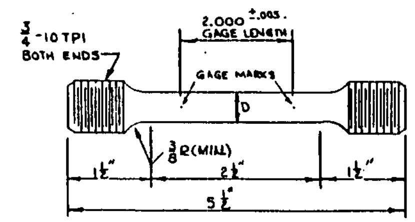
VPF # 1811-14

	MARK	REQ'D PC.	DESCRIPTION	LENGTH FT.	IN.	SPEC.
		36	505 TENSILE TEST			MS-1
			SPECIMENS M/F TENSILE			A533
			BLANKS AS SHOWN			GRBCL1
			SPECIMENS TESTED BY			FBX
			CB&I IN ACCORDANCE WITH			
			ATTACHMENT B PAR. 2.2.2 SPEC. 21A1112			

NOTES:
1. PWHT @ 1150°F PLUS 25°F OR MINUS 50°F FOR 50 HRS.

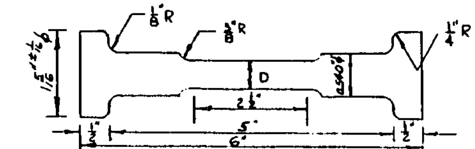


TEST AT ROOM TEMPERATURE					TEST AT 550°F					TEST AT 650°F				
MARK	TENSILE STR. (PSI)	YIELD STR. (PSI)	% ELONG.	REDUCTION OF AREA	MARK	TENSILE STR. (PSI)	YIELD STR. (PSI)	% ELONG.	REDUCTION OF AREA	MARK	TENSILE STR. (PSI)	YIELD STR. (PSI)	% ELONG.	REDUCTION OF AREA
1 G	89 400	65 700	24	68.8	1 D	83 100	60 000	21	66.8	1 A	83 000	57 400	23	66
2 G	86 500	65 000	24	68	2 D	78 400	57 500	19	58.3	2 A	81 400	56 200	24	67
3 G	87 400	65 100	24	69.6	3 D	79 500	58 700	21	66	3 A	83 100	57 400	23.5	68.8
4 G	92 700	70 100	23	70.5	4 D	83 900	62 200	20	66.1	4 A	86 700	60 400	24	69
1 H	88 900	66 000	24	68.2	1 E	80 900	58 700	21	64.6	1 B	82 600	57 800	21.5	63.1
2 H	85 700	64 500	24	70.5	2 E	79 200	57 700	21	67.5	2 B	81 000	56 400	20.5	60.4
3 H	87 000	66 500	24.5	69	3 E	79 800	58 400	21	65.8	3 B	82 900	57 200	23	64.9
4 H	92 200	70 500	23	69.6	4 E	84 700	63 000	20	67.5	4 B	86 700	60 700	23.5	69.5
1 J	88 400	65 500	24.5	67.8	1 F	81 100	58 800	21	66.3	1 C	83 000	55 700	23.5	67
2 J	86 700	64 500	24.5	69.1	2 F	78 900	57 500	21	66.3	2 C	80 900	56 600	22.5	65
3 J	87 400	65 200	24.5	70.5	3 F	79 000	57 500	21.6	66	3 C	82 400	56 900	23	67.6
4 J	92 500	69 900	24	70.5	4 F	84 400	62 200	21.5	67.7	4 C	86 900	61 000	22.5	69



NOTES:
D = 0.500 ± 0.010 DIA.

TENSILE SPECIMEN FOR TESTS @ 550°F & 650°F



TENSILE SPECIMEN FOR TESTS AT ROOM TEMPERATURE

Approved by GE/APED and released for fabrication 11/3/66

CHICAGO BRIDGE & IRON COMPANY
FABRICATION TEST FOR NUCLEAR REACTOR FOR GENERAL ELECTRIC CO. FOR NORTHERN STATES POWER CO. MONTICELLO, MINN.
CONTRACT NO. 9-5624
S. L. WALES
DWG. NO. TS REV 3

VPF # 1811-15

EXHIBIT 3

TENSILE TESTS
SPECIMENS OF 80 PERCENT PLATE THICKNESS

1811-353-1

Tensile Tests

Specimens of 80 Percent Plate Thickness

Nuclear Reactor Vessel

GE/APED for Northern States Power Company

Monticello, Minnesota

for

CHICAGO BRIDGE AND IRON COMPANY

Contract 9 - 5624

Richard N. Wright, III
Professional Engineer
New York License 035399

Department of Civil Engineering
University of Illinois
Urbana, Illinois
January 1968

I. Introduction

Test procedures and results are described for tests conducted for Chicago Bridge and Iron Company of six 80 percent thickness tension specimens for Nuclear Reactor Vessel GE/APED for Northern States Powei Company, Monticello, Minnesota. The tests were conducted at the same time as similar tests for Nuclear Reactor Vessel GE/APED for Central Vermont Power Company, Vernon Dam, Vermont. Facilities of the Department of Civil Engineering, University of Illinois, Urbana, Illinois were used in accord with a Memorandum Agreement for Commercial Tests between the Department and the Chicago Bridge and Iron Company. R. N. Wright, Associate Professor of Civil Engineering, supervised the testing. G. K. Sinnamon, Professor of Civil Engineering, and V. J. McDonald, Associate Professor of Civil Engineering and Principal Research Engineer, participated in planning and conduct of the tests.

Instrumentation and test procedures are described in the following section. Test results are described in the last section.

2. Instrumentation and Test Procedures

Test specimens were prepared by Chicago Bridge and Iron Company. Dimensions are given in their drawing T6 Rev 1 for Contract No. 9-5624 which is reproduced here as Fig. 1. Gage diameter was 4-5/16 in. and gage length 13 in. Specimens were delivered to the Department of Civil Engineering on September 11, 1967 and stored in Talbot Laboratory adjacent to the testing machine until tested during the week of January 8, 1968. Test procedures conformed with ASTM E8 66. Test temperatures ranged from 70 to 75 degrees Fahrenheit.

The testing machine used was the University of Illinois 3,000,000 lb. capacity universal testing machine. Loads were recorded from the load indicator of the machine. Ames dial indicators with .0001 in. divisions were used in measuring elongations from zero load to approximately 1 percent strain; and Ames dial indicators with .001 in. divisions were used from zero load to maximum load. Initial gage lengths and elongations after rupture were measured using a steel scale with .01 in. divisions. Initial gage diameters and diameters after rupture were measured using micrometers with .001 in. divisions.

Figure 2 shows a specimen in place in the testing machine with the dial indicators supported by a split ring and angle device. Diametrically opposed, spring loaded, gage points fit holes 1/16 in. diameter by 1/8 in. deep drilled into the specimens to support the rings. A third gage point between the diametrical ones prevents rocking of the ring. The angles attached to the rings hold the two .001 in. division Ames dials at 4 1/4 in. from the axis of the specimen and the two .0001 in. division Ames dials at 6 1/4 in. from the axis of the specimen. Indicators are pulled by copper wires attached to a similar split ring and angle device. Figure 3 shows indicators in place during loading and the television cameras used to read elongations. Figure 4 shows recording of load from the load measuring system of the testing machine and recording of elongations from closed circuit television receivers.

During the first two of the six tests, SR-4 electrical resistance strain gages were used to measure strain prior to yield in order to check upon the accuracy of the dial indicator system. SR-4 gages showed slightly greater strain during the first loading increment (50 to 100 kips) than the dial indicators; thence to yield essentially identical changes in strain were recorded by the two procedures. The discrepancy in the initial increments is attributable to reseating of the gage points supporting the dial indicators following the reversal of strain direction during the preliminary steps of loading described below. Only strains obtained from elongation measurements with the dial indicators are reported here.

Preliminary steps of the testing consisted of centering the specimen in the upper head of the machine, recording initial elongations at zero load, fastening the lower head of the specimen and loading to 100 kips to set the grips, reducing load to 50 kips and reading elongations which were used as base values in reducing stress-strain data. Elastic range loading began with increase of load to 100 kips and reading of elongation, followed by increase of load and elongation reading in 100 kip increments. Upon noticeable yielding, a slow deformation rate was maintained, load and elongation were recorded at intervals of approximately .01 in. elongation until pronounced strain hardening at an elongation of about .1 in. Then load was reduced and the .0001 in. dial indicators were removed. Continuous deformation was resumed; load and elongation were recorded at intervals of about .05 in. elongation until maximum load was observed. Dial indicators were then removed from the specimen and it was deformed to rupture. In the first two tests somewhat fewer readings were made in the postyield range. In the inelastic range to maximum load, strain rate did not exceed .01 in./in./minute. In the elastic range stress rate did not exceed 10,000 psi/minute.

In the first test the lower ring came loose twice during the postyield range of testing. The deformed gage length was measured to 0.01 in. accuracy after the dial indicators were removed at maximum load. This measurement provided a basis for computing strains from dial readings for the majority of the postyield region; a small region of uncertainty is shown by dotted lines in Fig. 5. The cause of the loosing of the lower ring was improper spring loading of the gage points. One more loosening of the lower ring occurred in the process of obtaining proper adjustment. It was in the second test , Fig. 6, at a stress of 81.9 ksi. It was determined that dial readings were not substantially affected by the loosening and replacement.

3. Test Results

Test results are summarized in Table 1. Shown for each specimen are: stress-strain curves, Fig. 5 through 10; photographs of the two fracture surfaces, Fig. 11 through 16; and photographs of the broken specimens with fracture surfaces fitted together, Fig. 17 through 22. Specimens are identified by the numbers provided by Chicago Bridge and Iron Company and an "OT No." assigned by the writer to facilitate identification of individual tests and specimens.

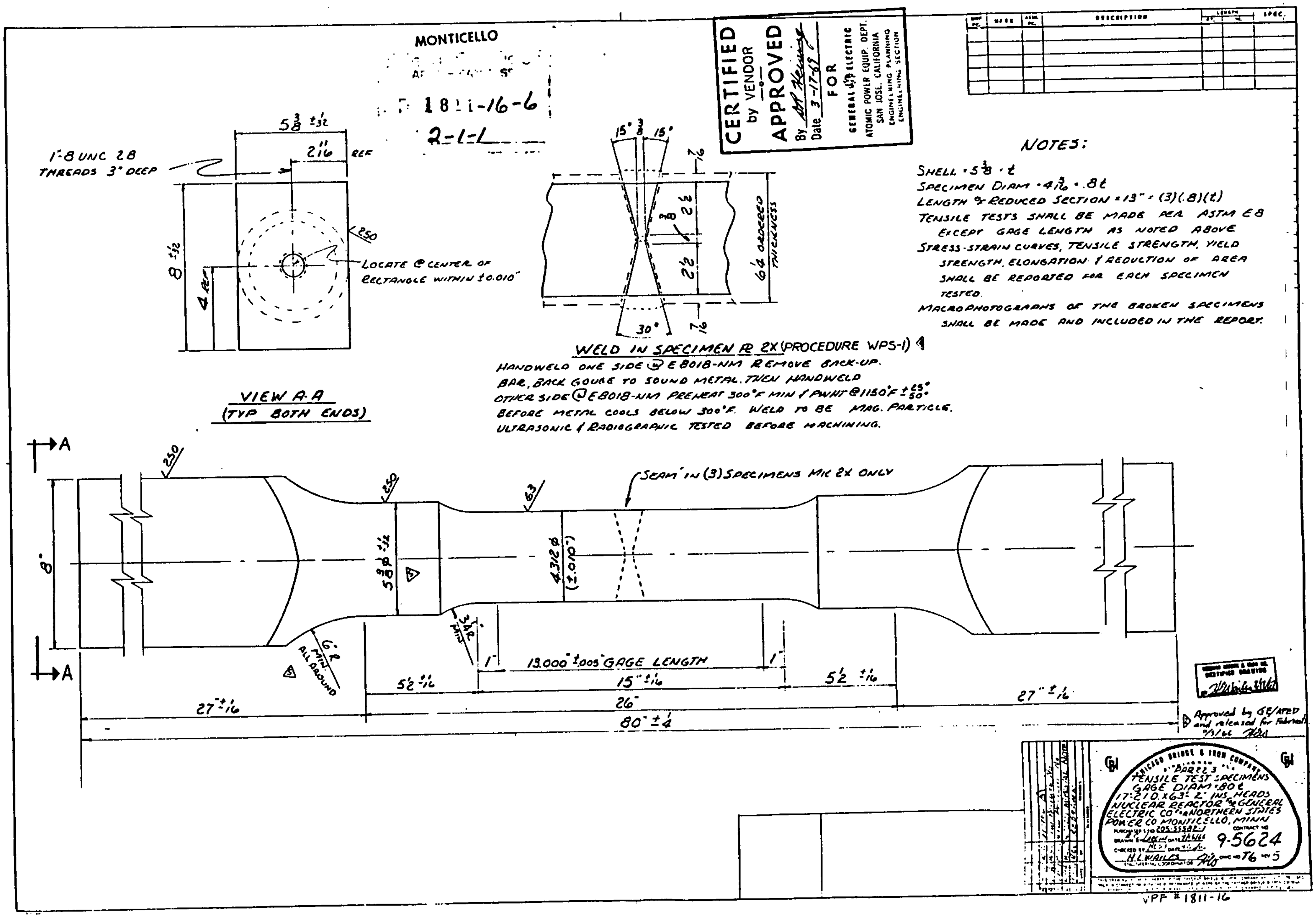
Table 1 shows that test results meet tensile requirements of ASTM A 533, Grade B, Class 1 steel. The elongation in 13 in. is not directly comparable to the standard elongation in 2 in. for a 1/2 in. diameter specimen. Larger elongation is observed because the gage length is only three times the diameter for these specimens. If, however, an additional 4-5/16 in. of gage length were considered to be present and to elongate by the 10 percent uniform strain typical of Fig. 5 through 10, the elongation in 17-1/4 in. would in every instance exceed 20 percent.

Welded specimens, denoted by T3-2X, showed substantially the same properties as the unwelded. It is apparent in Fig. 20 through 22 that fracture of the welded specimens was ductile and occurred in the base metal well away from the weld. A clear indication of weld yielding at a stress of 67 ksi appears in Fig. 10. Possible weld yielding at 64 ksi is suggested by the stress-strain curve shown in Fig. 9; for the stress-strain curve of Fig. 8, yielding of base metal and weld appears to have occurred simultaneously.

TABLE 1. SUMMARY OF TEST RESULTS

Specimens 5624 A 0998 2	Yield Strength[a] ksi	Tensile Strength ksi	Elongation in 13 inches percent	Reduction in Area percent
T3-2				
OT 1	63.0	84.4	28.3	61.2
OT 2	62.0	84.2	25.8	61.1
OT 11	61.3	83.1	23.7	62.4
T3-2X				
OT 5	65.8	85.6	25.9	61.0
OT 8	63.7	83.6	26.7	60.9
OT 9	64.8	84.5	25.8	58.9

[a]Yield strength at 0.2 percent offset.


MONTICELLO
1811-16-6
2-1-L
CERTIFIED by VENDOR APPROVED
By
Date 3-17-69
FOR GENERAL ELECTRIC
ATOMIC POWER EQUIP. DEPT.
SAN JOSE, CALIFORNIA
ENGINEERING PLANNING
ENGINEERING SECTION
DESCRIPTION
LENGTH
SPEC.
NOTES:
SHELL - 5 3/8 - t
SPECIMEN DIAM - 4 5/16 - .8t
LENGTH & REDUCED SECTION = 13" = (3)(.8)(t)
TENSILE TESTS SHALL BE MADE PER ASTM E8 EXCEPT GAGE LENGTH AS NOTED ABOVE
STRESS-STRAIN CURVES, TENSILE STRENGTH, YIELD STRENGTH, ELONGATION & REDUCTION OF AREA SHALL BE REPORTED FOR EACH SPECIMEN TESTED.
MACROPHOTOGRAPHS OF THE BROKEN SPECIMENS SHALL BE MADE AND INCLUDED IN THE REPORT.
1"-8 UNC 2B THREADS 3" DEEP
5 3/8 ±1/32
2 11/16 REF
8 ±1/32
4 REF
250
LOCATE @ CENTER OF RECTANGLE WITHIN ±0.010"
15° 3/8 15°
7/16
2 1/2
2 1/2
6 1/4 ORDERED THICKNESS
30°
WELD IN SPECIMEN PL 2X (PROCEDURE WPS-1)
HANDWELD ONE SIDE W/ E8018-NM REMOVE BACK-UP BAR, BACK GOUGE TO SOUND METAL. THEN HANDWELD OTHER SIDE W/ E8018-NM PREHEAT 300°F MIN & PWHT @ 1150°F +25° -50° BEFORE METAL COOLS BELOW 300°F. WELD TO BE MAG. PARTICLE, ULTRASONIC & RADIOGRAPHIC TESTED BEFORE MACHINING.
VIEW A-A
(TYP BOTH ENDS)
A
A
250
250
63
SEAM IN (3) SPECIMENS MK 2X ONLY
8"
5 3/8 ø ±1/32
4.312 ø (±.010")
3/4 R MIN
6" R MIN. ALL AROUND
1"
13.000" ±.005 GAGE LENGTH
1"
5 1/2 ±1/16
15" ±1/16
5 1/2 ±1/16
27" ±1/16
26"
27 ±1/16
80" ±1/4
Approved by GE/APED and released for Fabrication
CHICAGO BRIDGE & IRON COMPANY
TENSILE TEST SPECIMENS
GAGE DIAM .80t
17'-2 1/0 x 63" 2" INS. HEADS
NUCLEAR REACTOR for GENERAL ELECTRIC CO. & NORTHERN STATES POWER CO MONTICELLO, MINN
9-5624
H.L. WAILES
T6
5
VPF # 1811-16

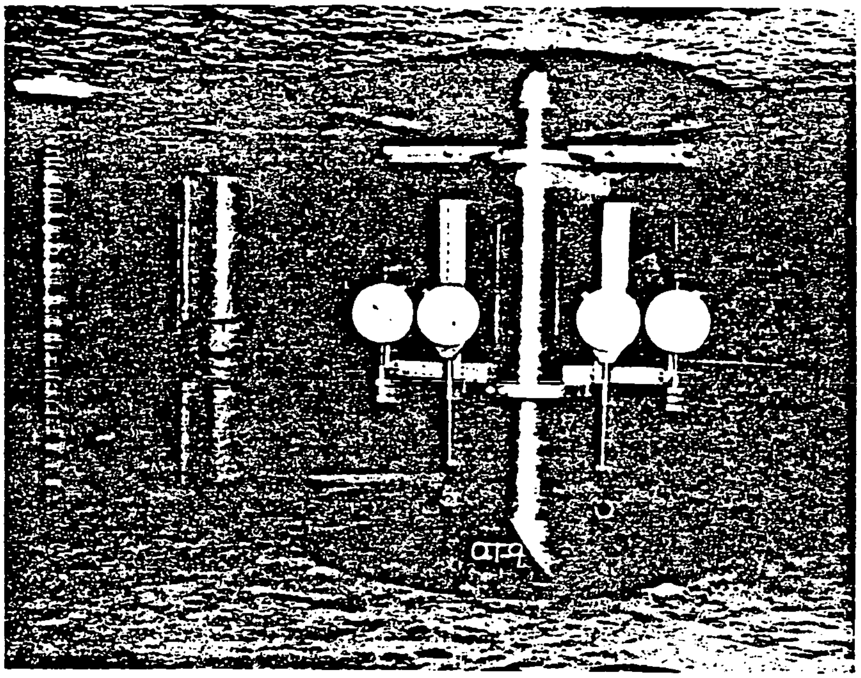


FIGURE 2. Specimen with Elongation Instrumentation

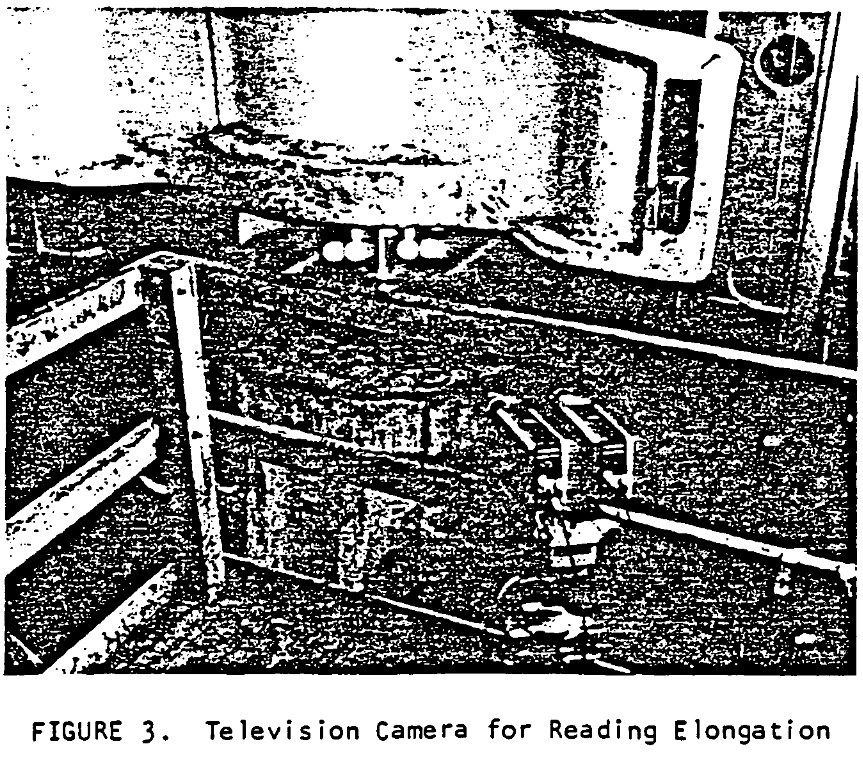


FIGURE 3. Television Camera for Reading Elongation

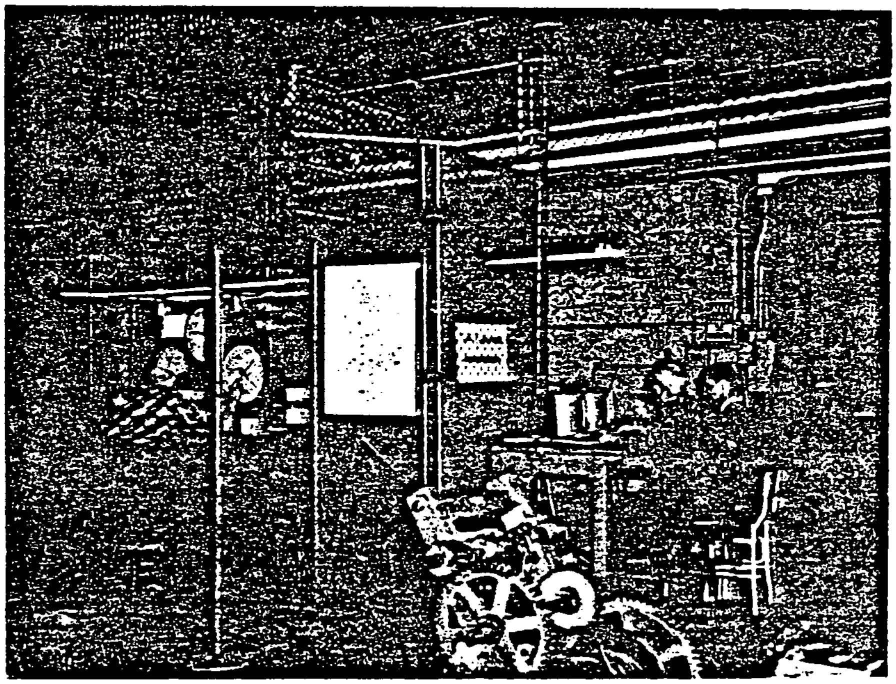


FIGURE 4. Recording of Load and Elongation

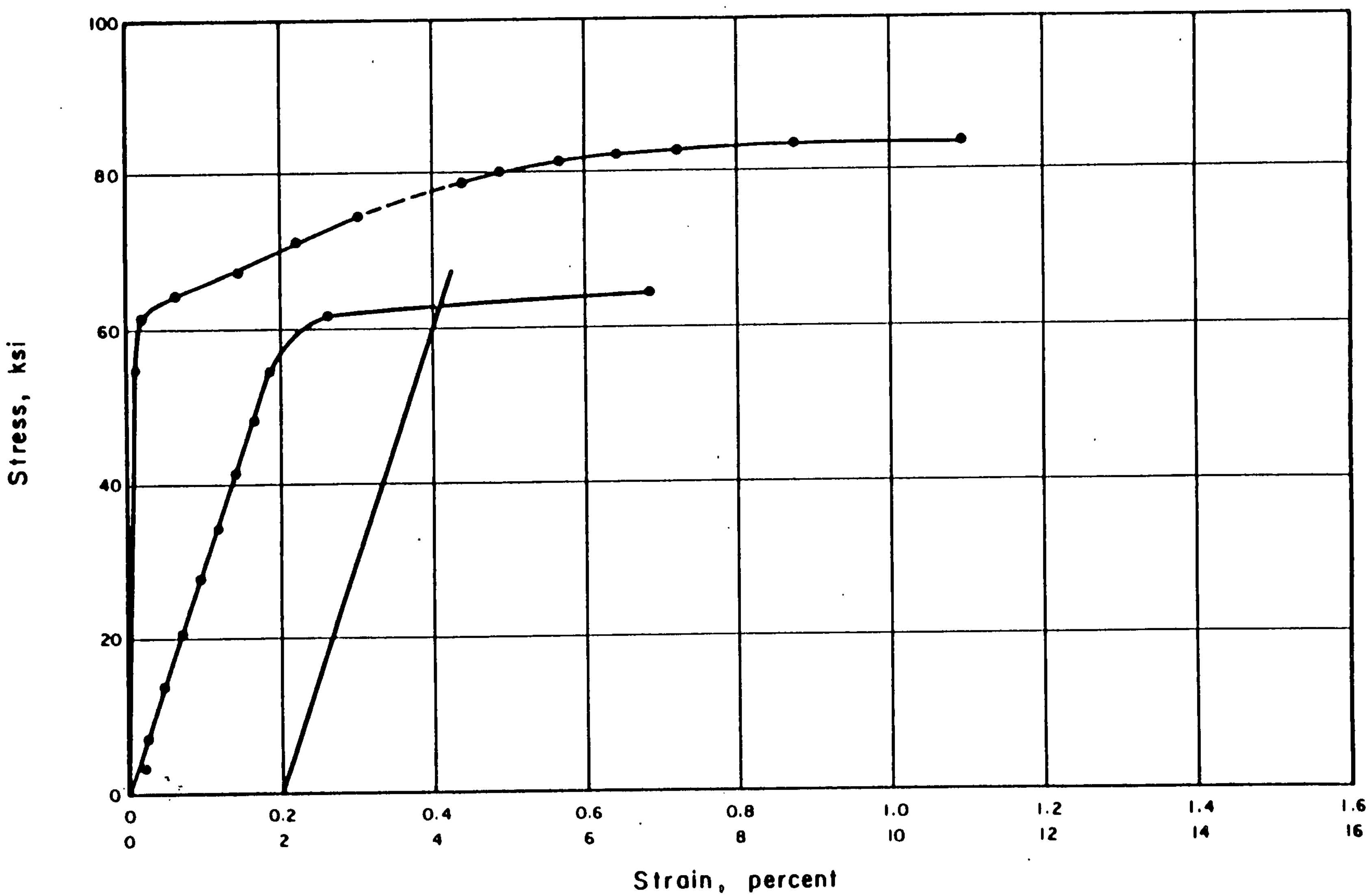


FIG. 5 SPECIMEN 5624 T3-2 A0998 2 OT I

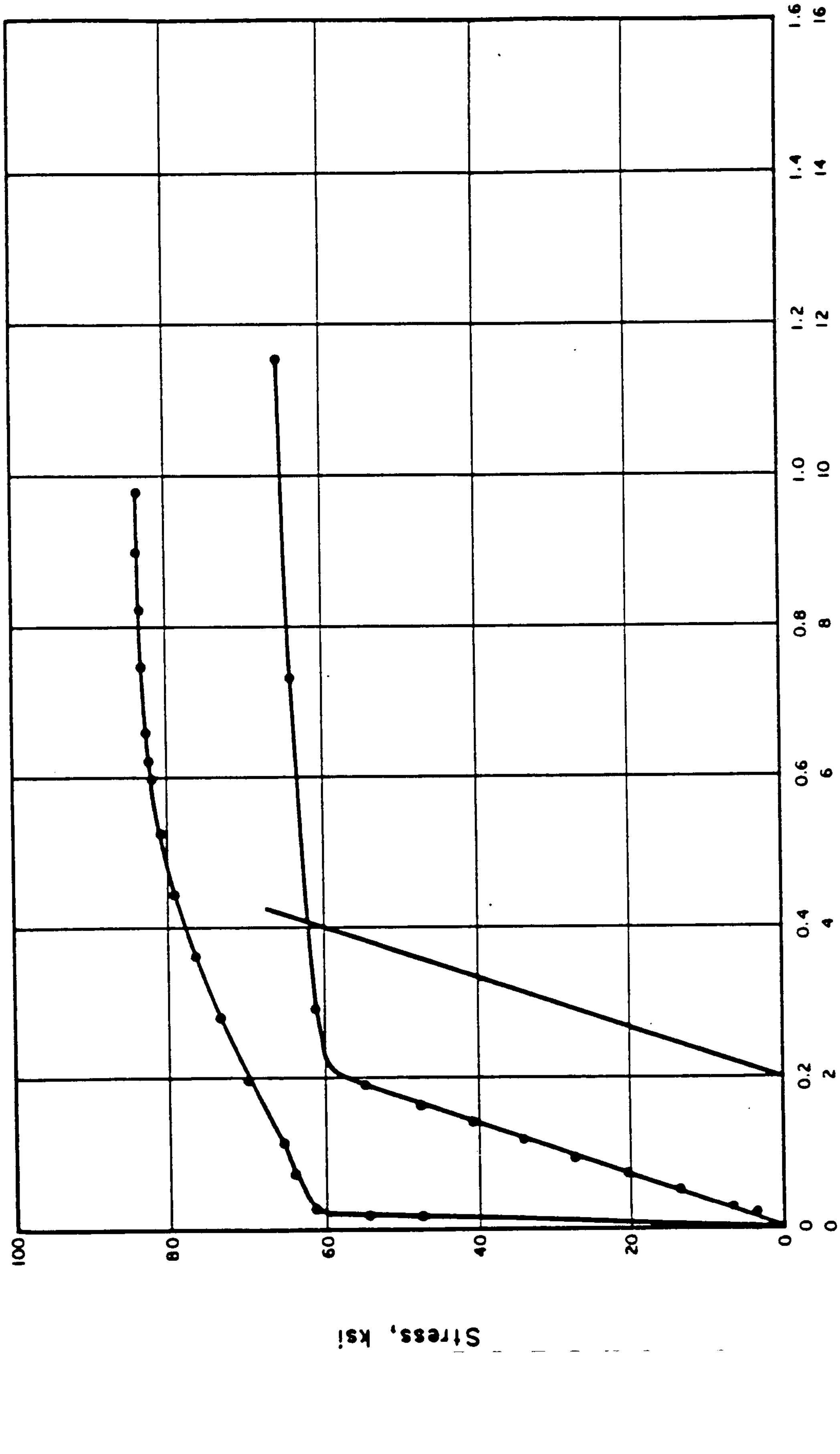


FIG. 6 SPECIMEN 5624 T3-2 A0998 2 OT 2

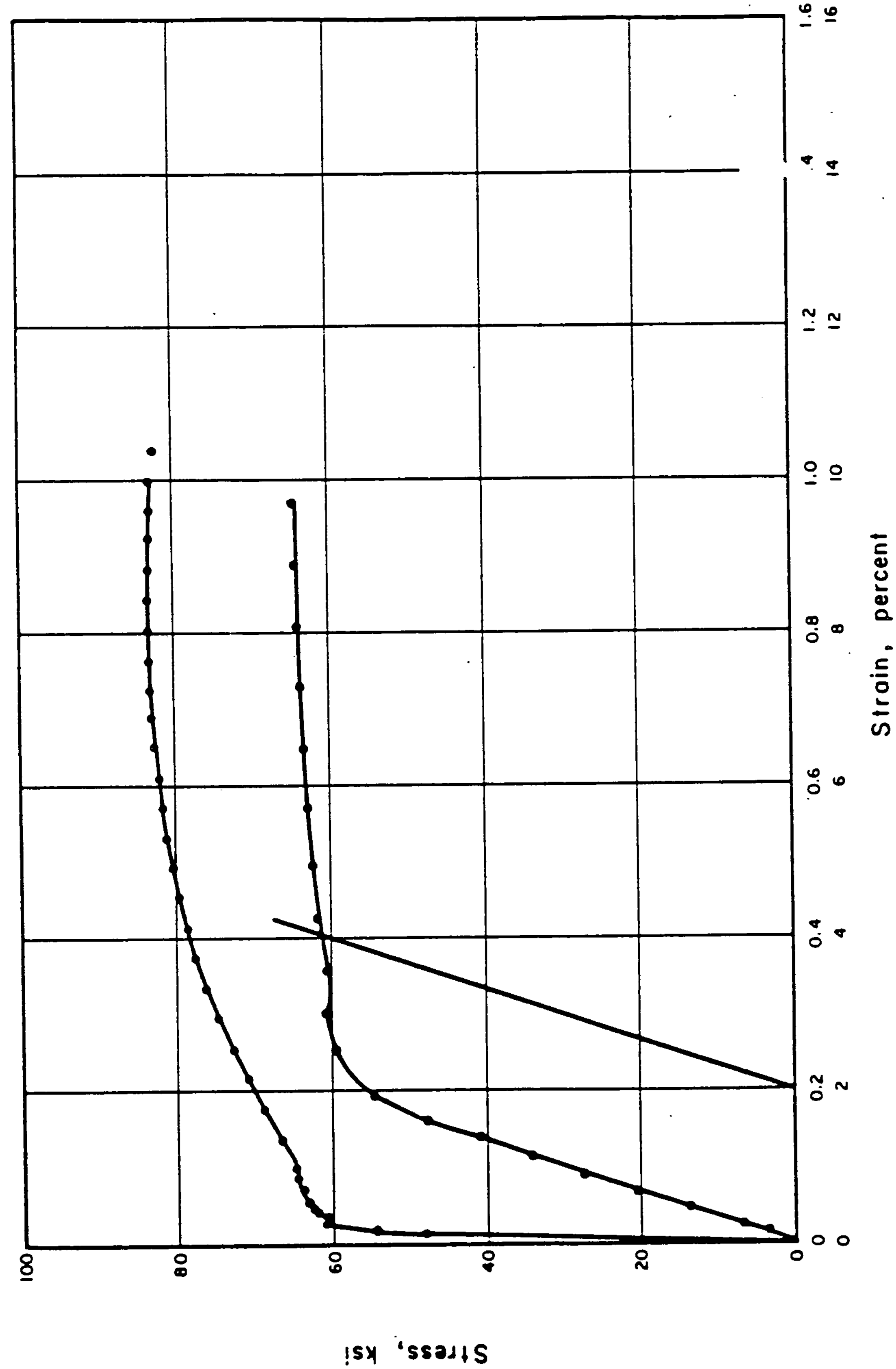


FIG. 7 SPECIMEN 5624 T3-2 A0998 2 OT 11

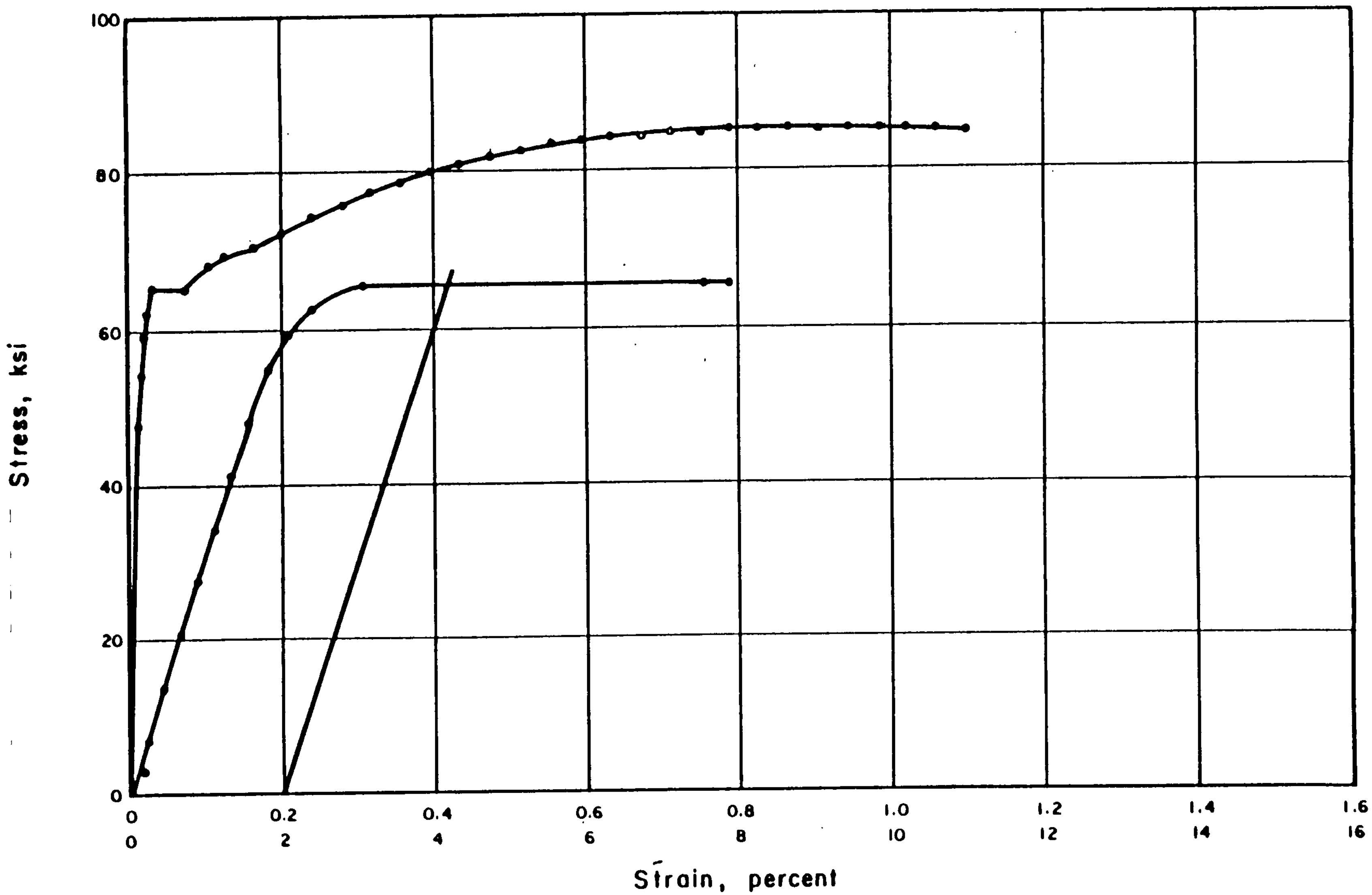


FIG. 8 SPECIMEN 5624 T3—2X A0998 2 OT 5

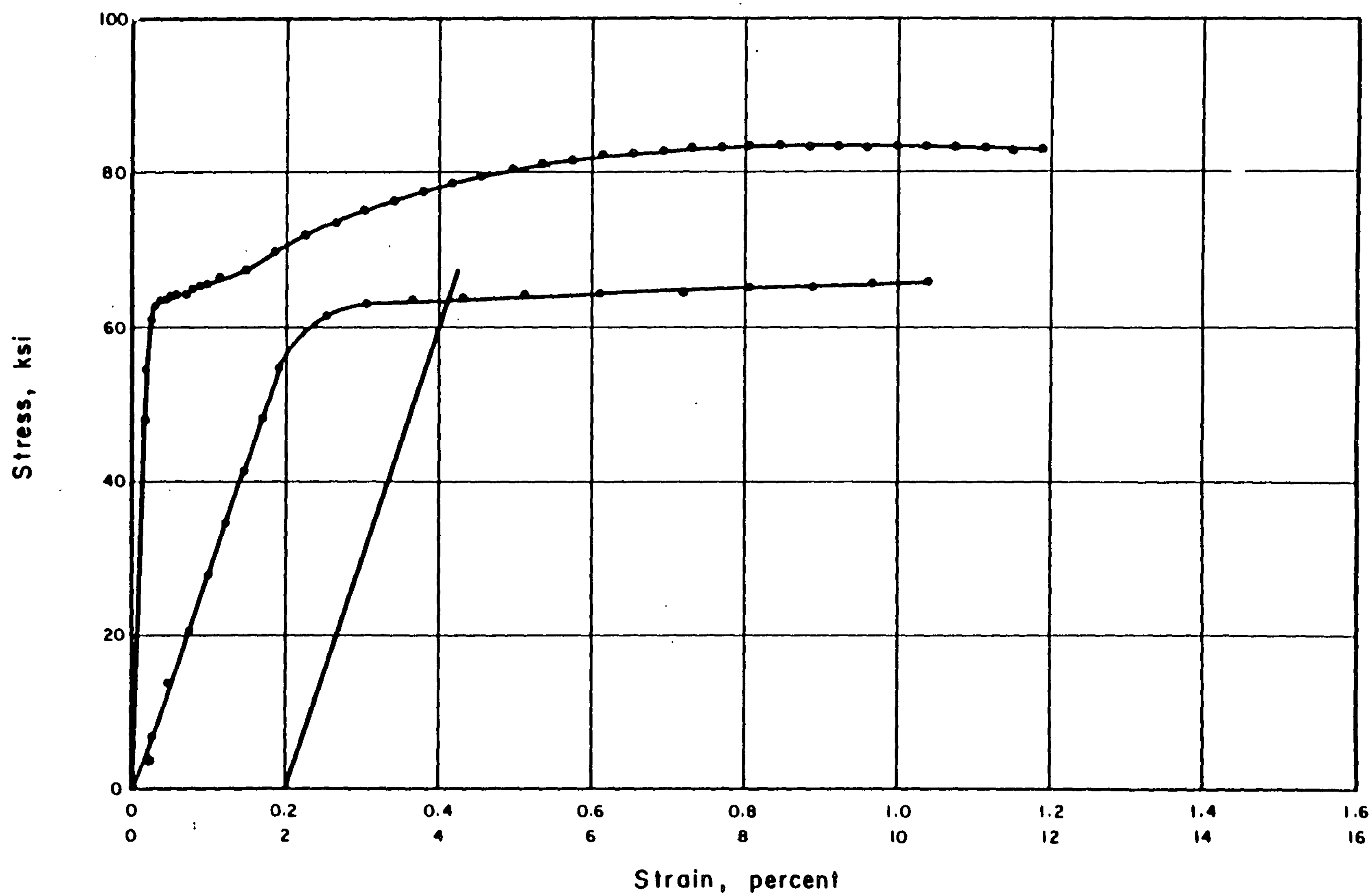


FIG. 9 SPECIMEN 5624 T3-2X A09982 OT 8

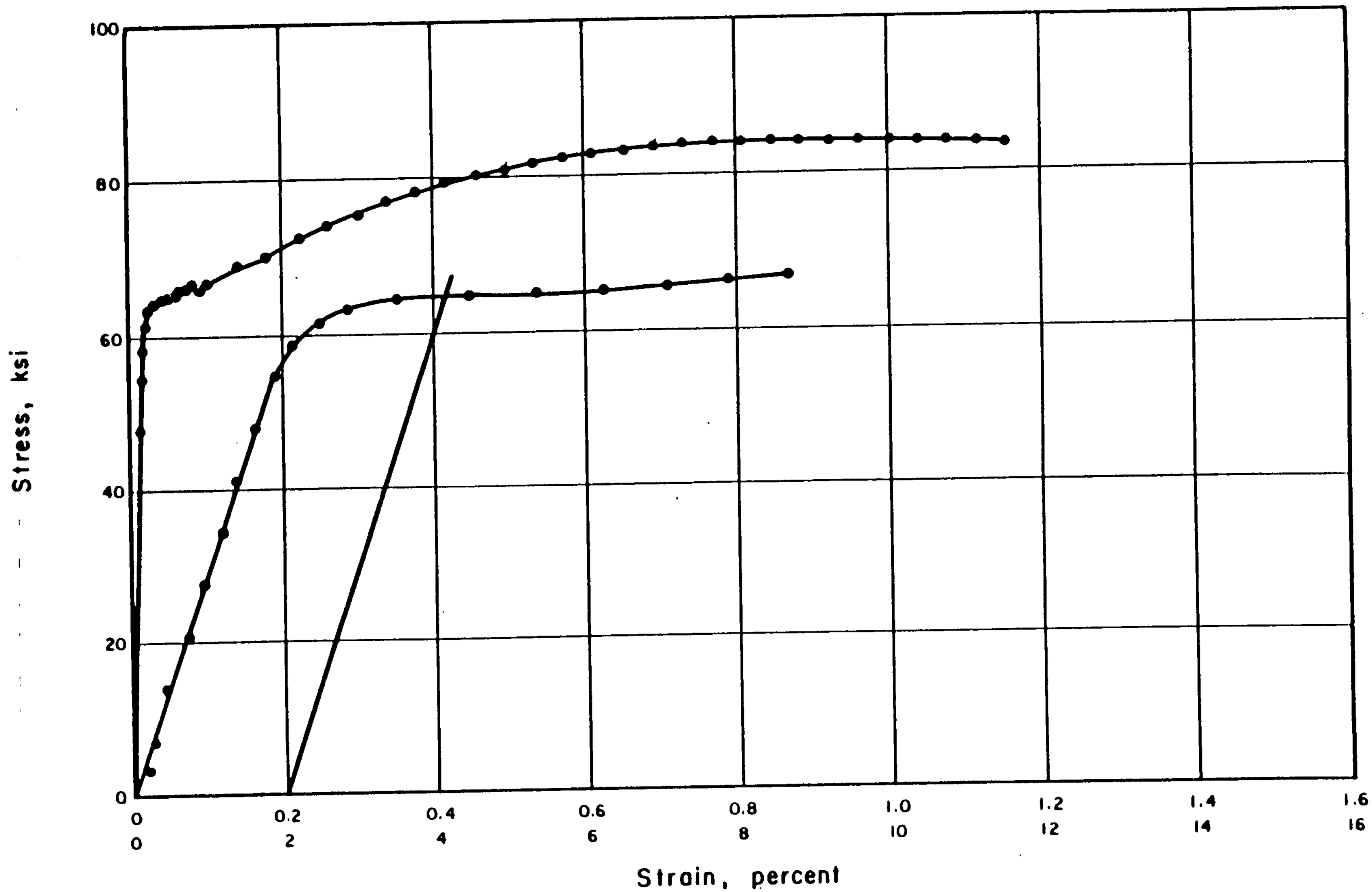
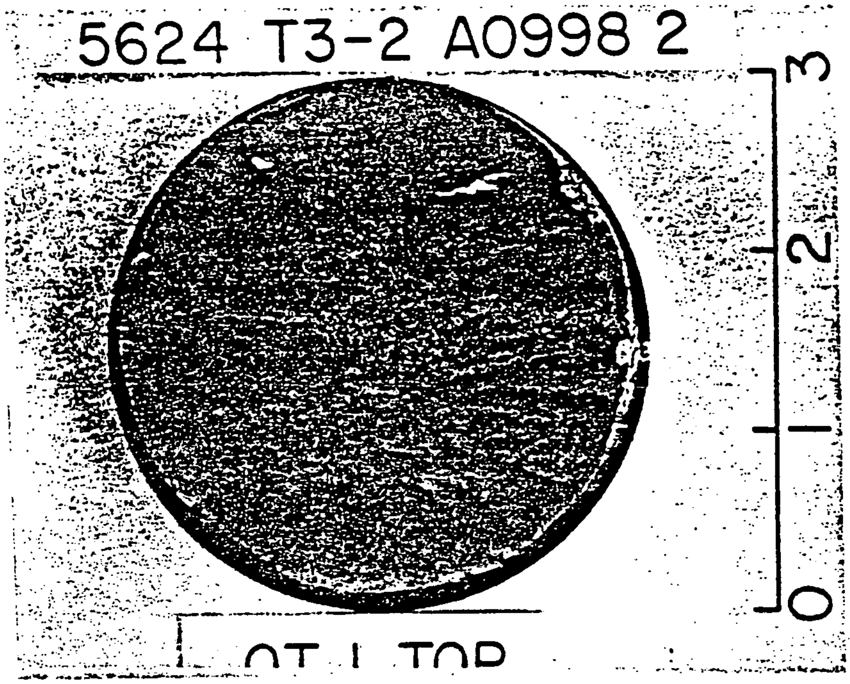


FIG. 10 SPECIMEN 5624 T3-2X A0998 2 OT 9



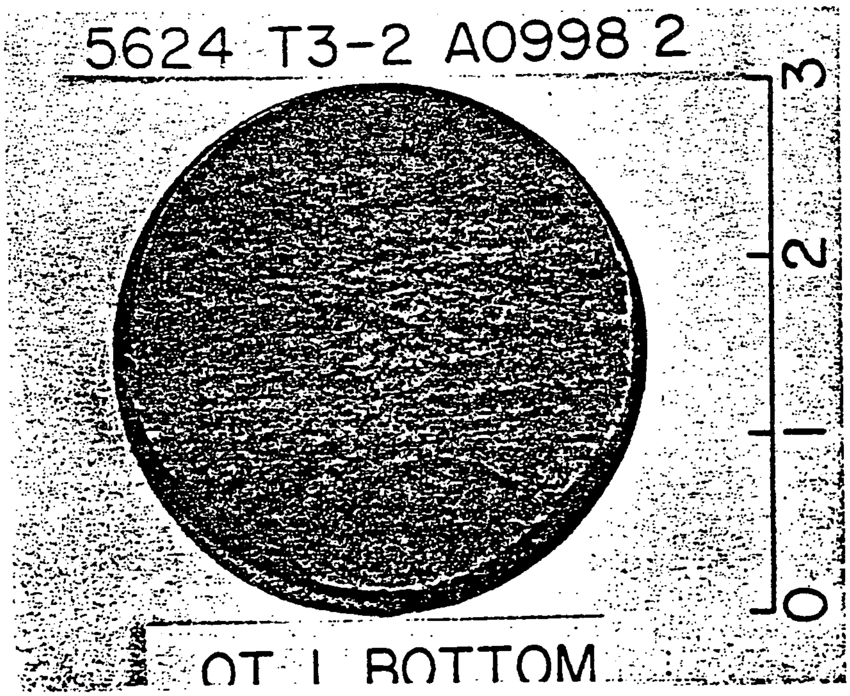
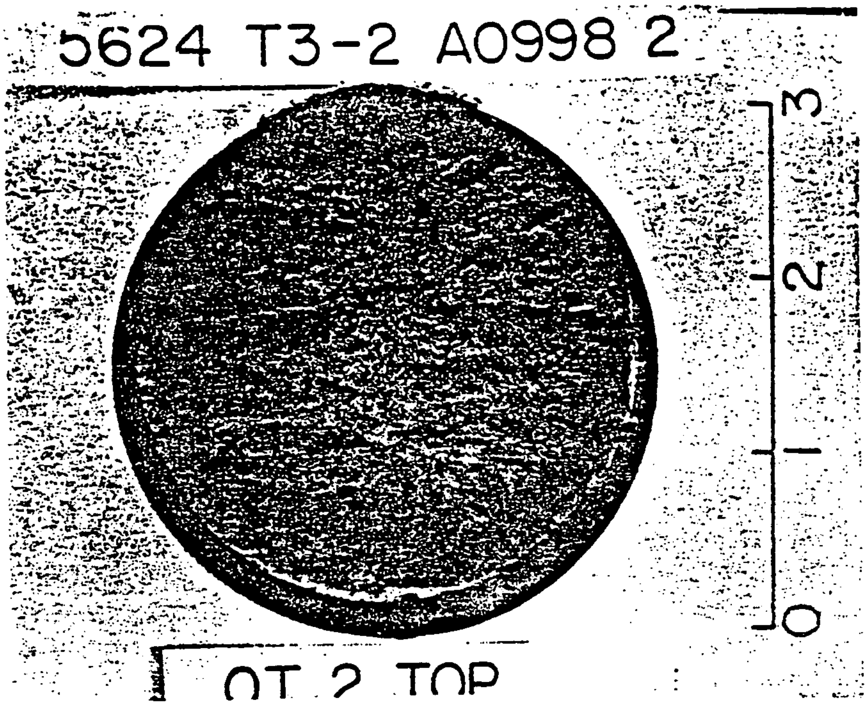


FIGURE 11. Fracture Surfaces, 5624 T3-2 A0998 2, OT 1



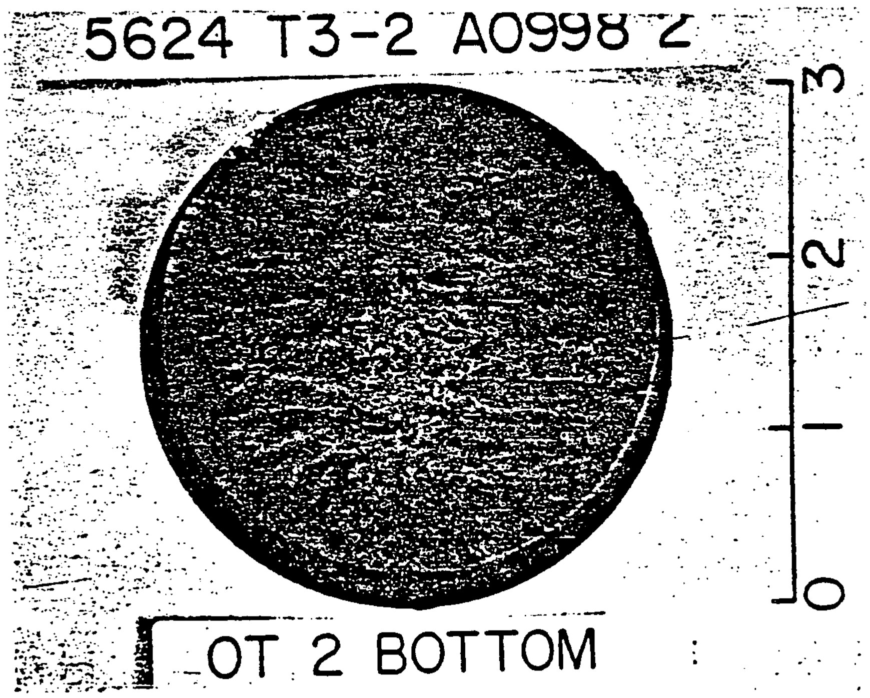
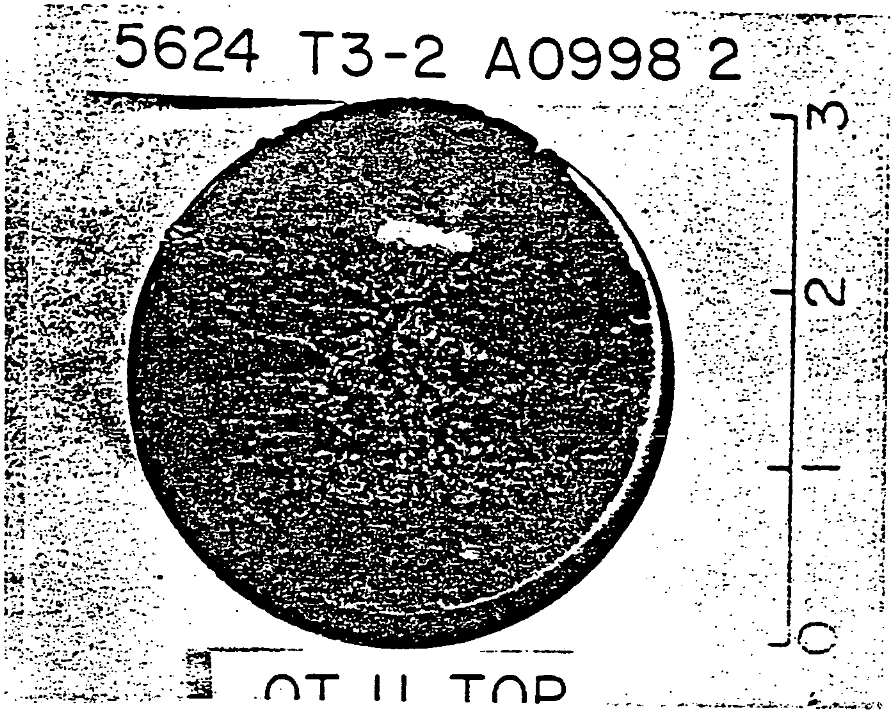


FIGURE 12. Fracture Surfaces, 5624 T3-2 A0998 2, OT 2



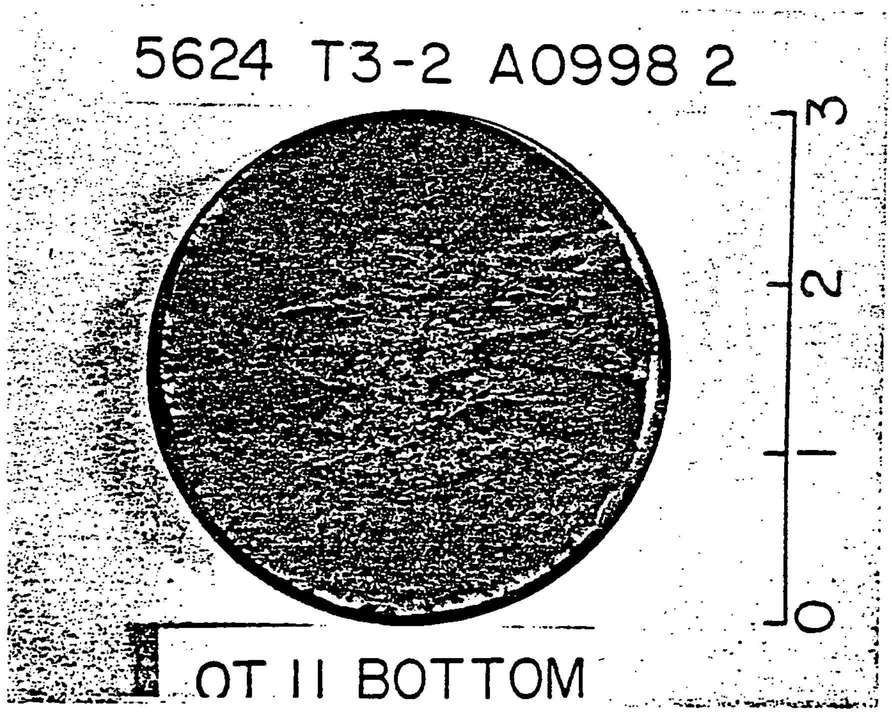


FIGURE 13. Fracture Surfaces, 5624 T3-2 A0998 2, OT 11

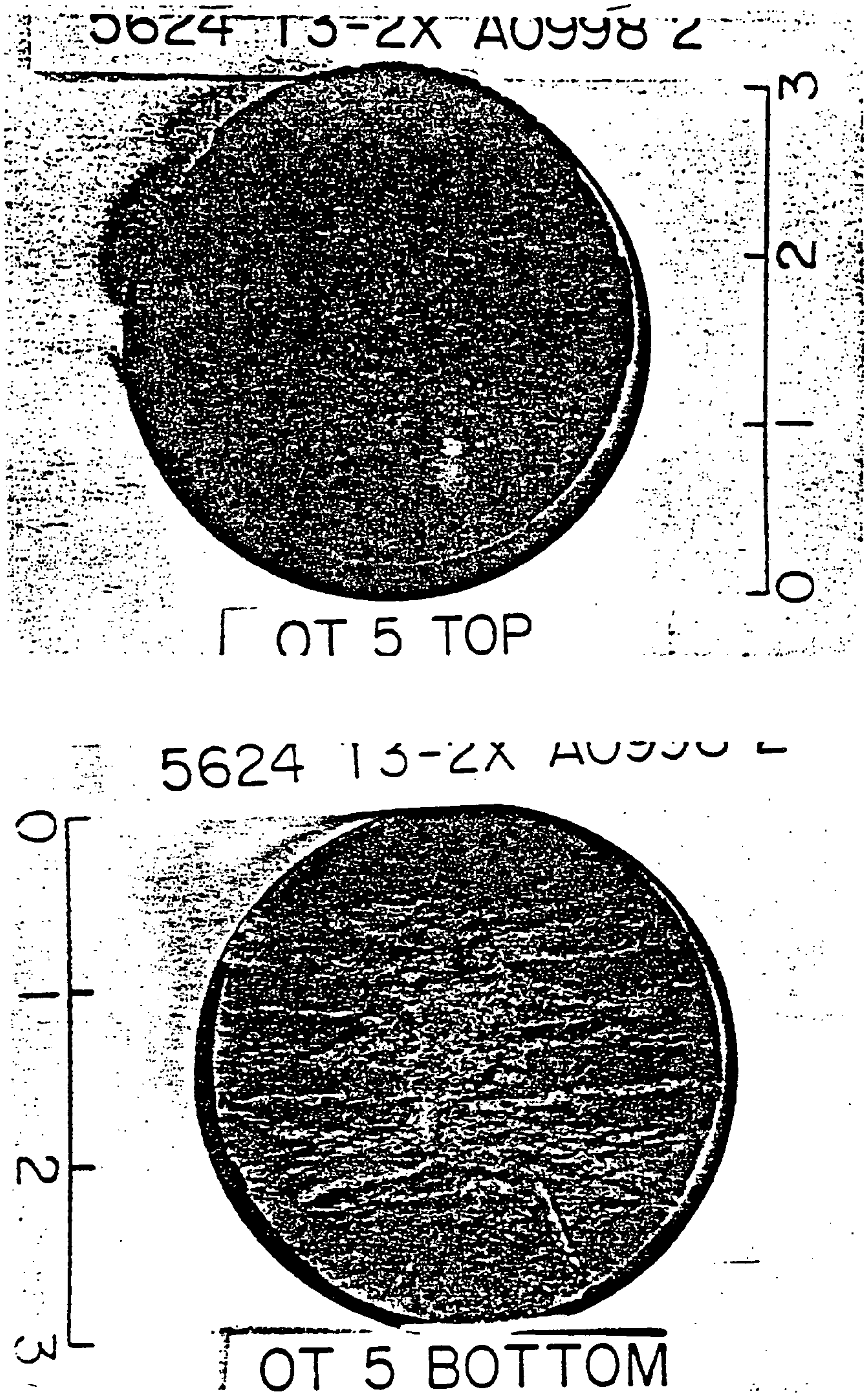


FIGURE 14. Fracture Surfaces, 5624 T3-2X A0998 2, OT 5

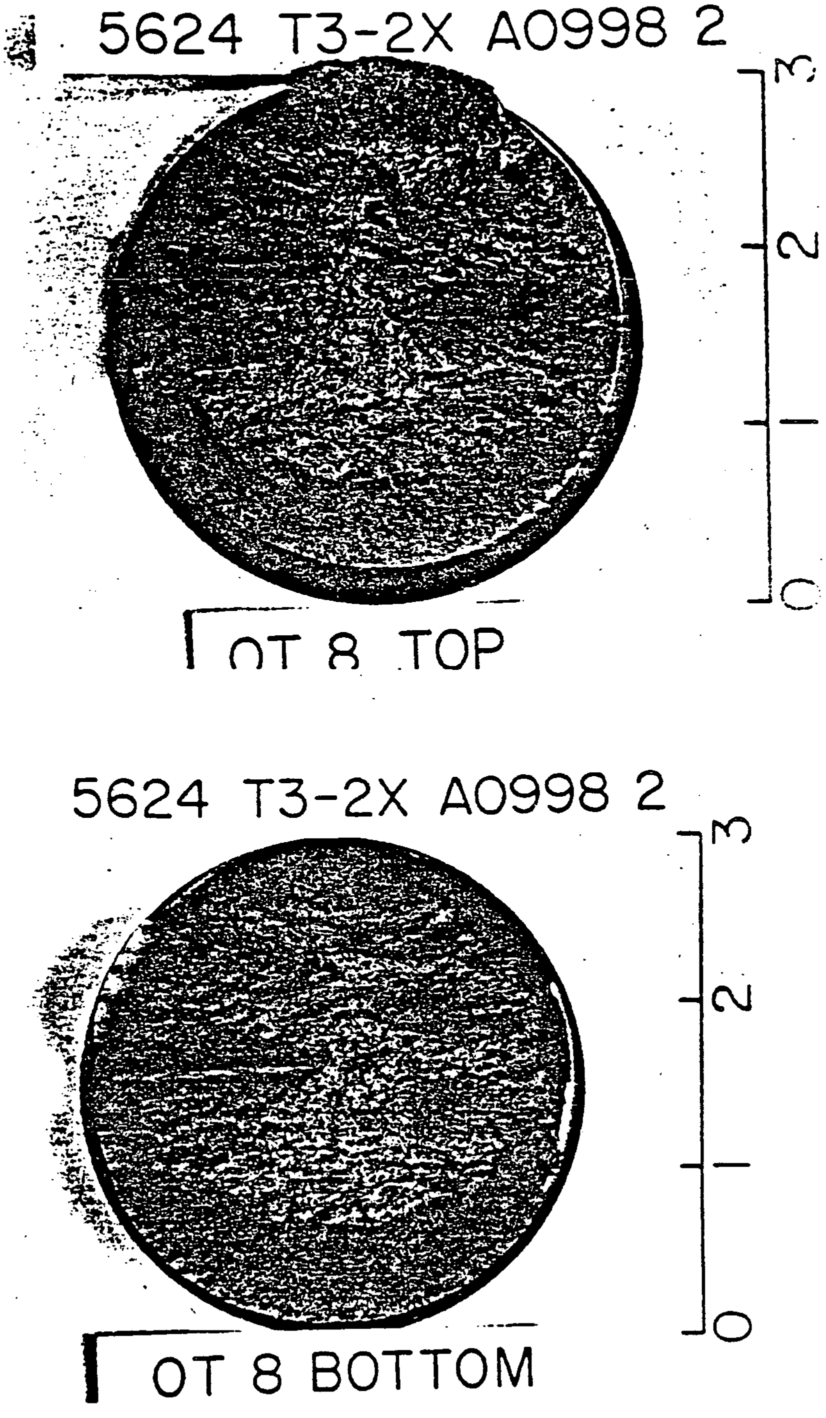
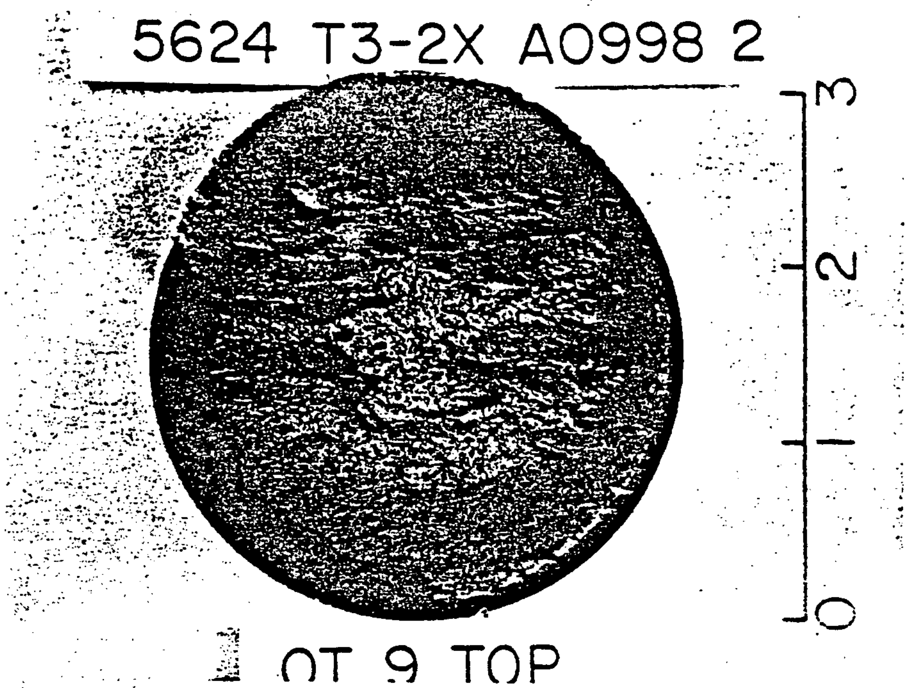


FIGURE 15. Fracture Surfaces, 5624 T3-2X A0998 2, OT 8



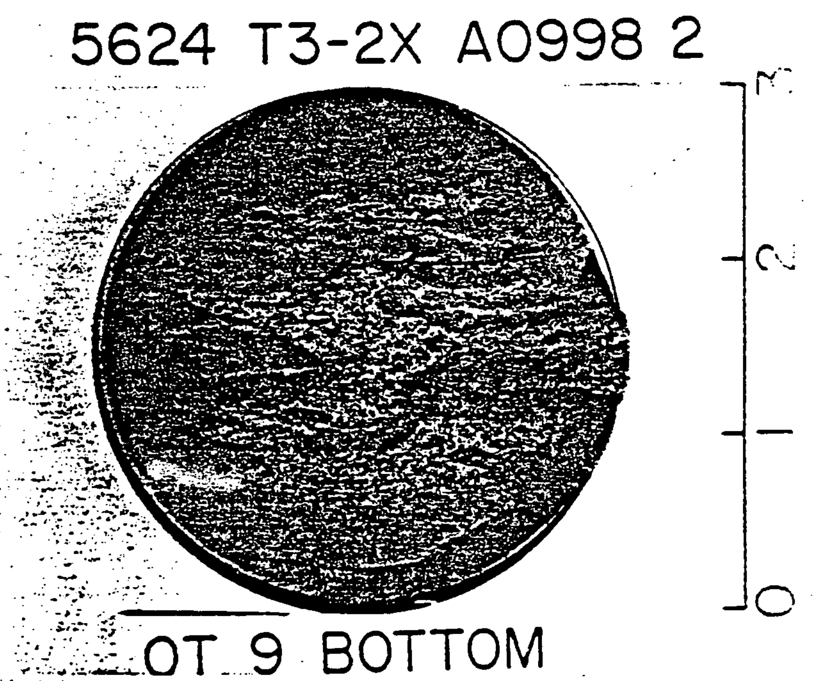


FIGURE 16. Fracture Surfaces, 5624 T3-2X A0998 2, OT 9

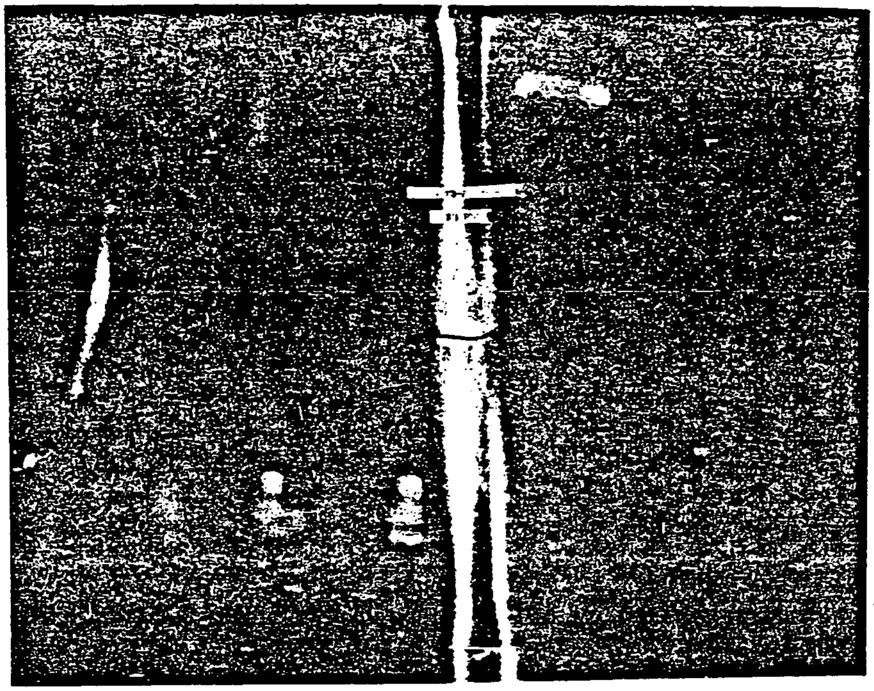


FIGURE 17. Fractured Specimen, 5624 T3-2 A0998 2, OT 1

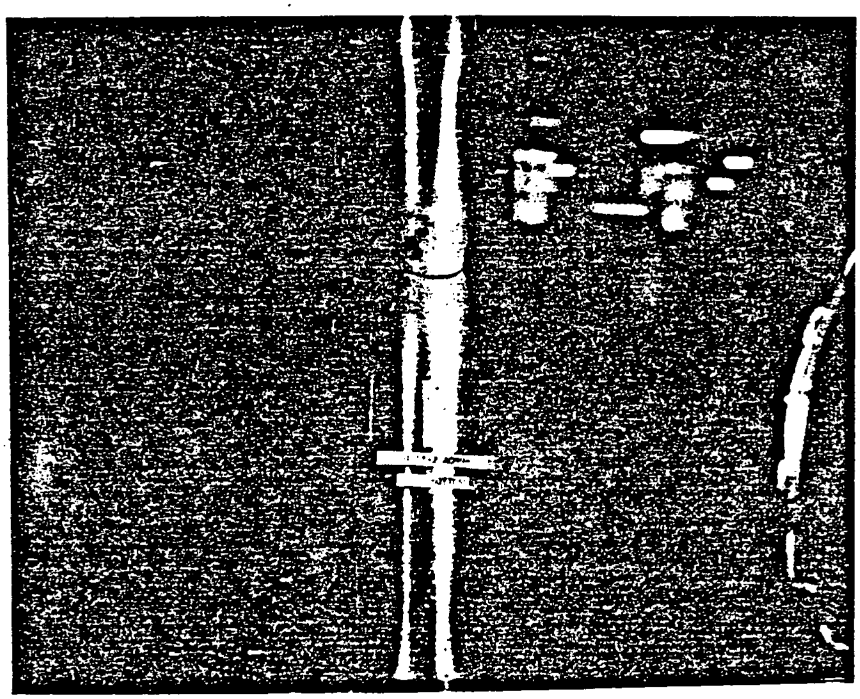


FIGURE 18. Fractured Specimen, 5624 T3-2 A0998 2, OT 2

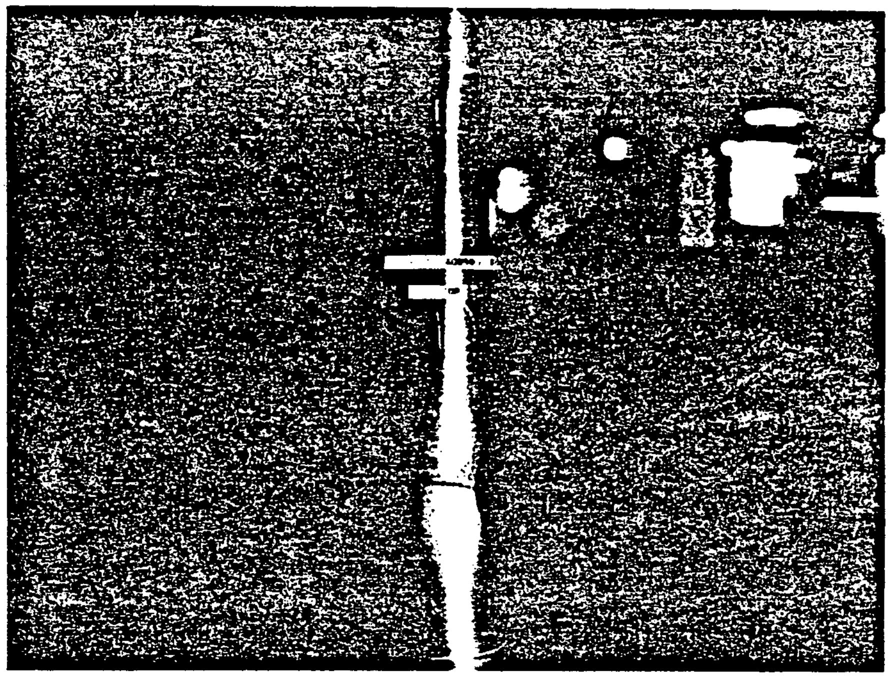


FIGURE 19. Fractured Specimen, 5624 T3-2 A0998 2, OT 11

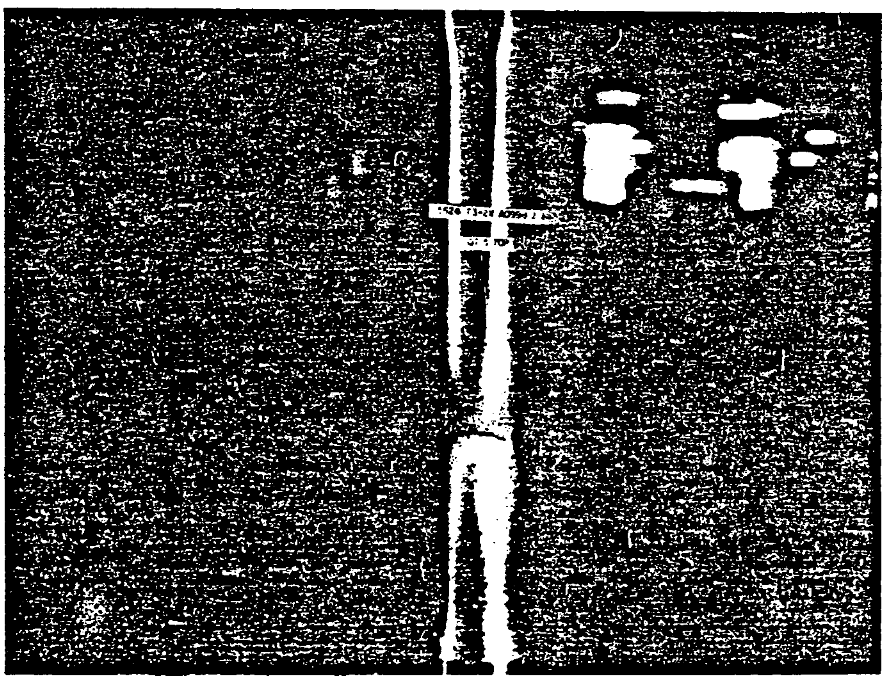


FIGURE 20. Fractured Specimen, 5624 T3-2X A0998 2, OT 5

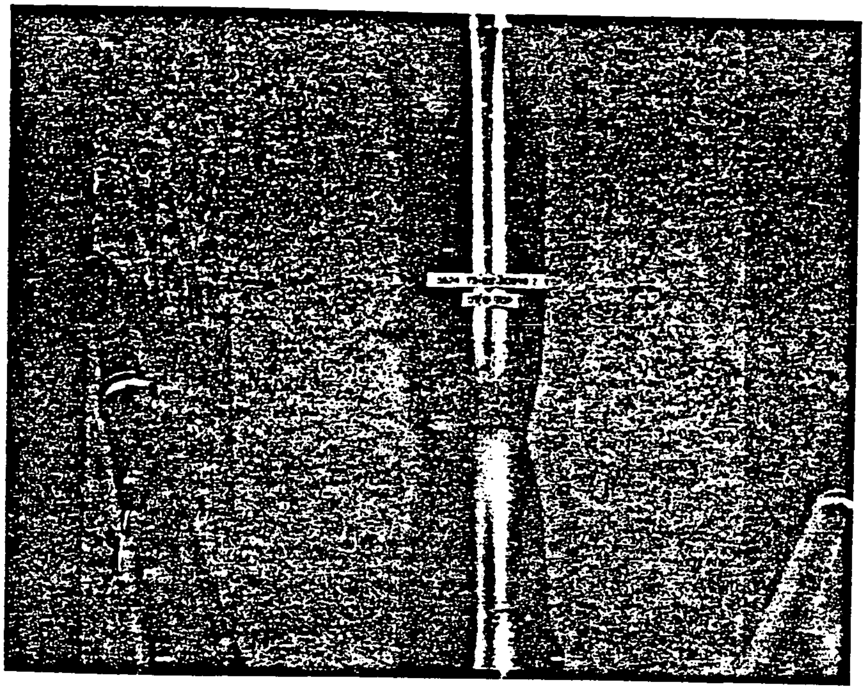


FIGURE 21. Fractured Specimen, 5624 T3-2X A0998 2, OT 8

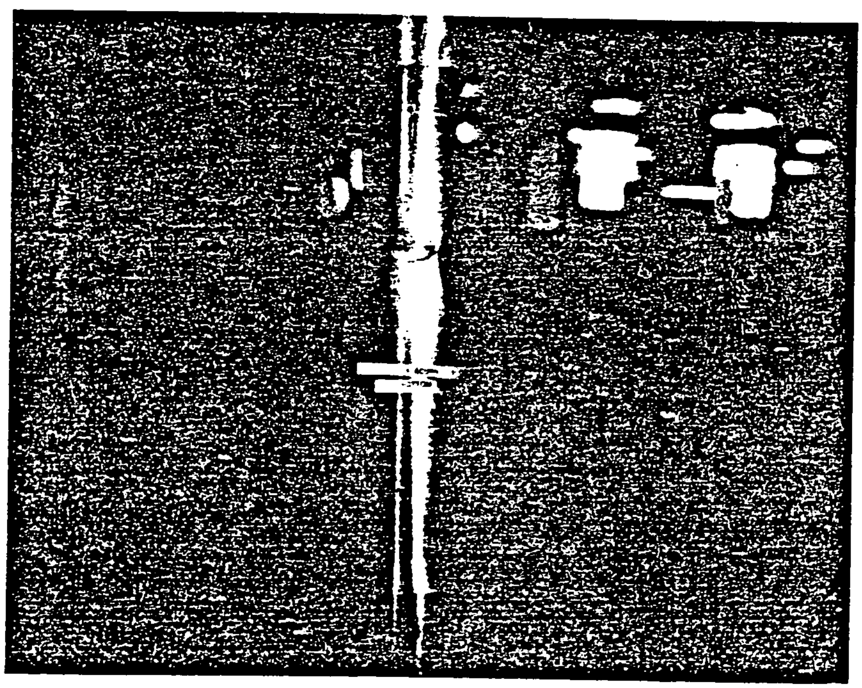


FIGURE 22. Fractured Specimen, 5624 T3-2X A0998 2, OT 9

Revised Copy 12-20-66 Revised Copy 1-9-67 Revised Copy 2-1-67 Revised Copy 3-3-67

LUKENS STEEL COMPANY

COATESVILLE, PA.

TEST CERTIFICATE

PURCHASER:
10. Chicago Bridge & Iron Co.
Mr. G.H. Putman, P.A.
P.O. Box 277
Birmingham, Ala. 35202

MILL ORDER NO.	CUSTOMER P.O.	
43211-1	5624 #2	MB 112166 EM

Affi:
DATE: 11-26-66 FILE NO. 1543
CONSIGNEE:
Same
Boyles, Ala.

SPECIFICATIONS:
A-533-65 Gr.B Class 1 Mod.by C.B.& I. Spec. MS-1 DTD 8/25/66 Fbx. 80000 Cont.# 9-5624

BEND TEST O.K. HOMOGENITY TEST O.K.

CHEMICAL ANALYSIS

MELT NO.	C	Mn	P	S	Cu	Si	Ni	Cr	Mo	V	Ti	XX	X		Grain Size
C1946	22	1.35	010	015		23	50		47			V.I.	P.Steel		T#7 B#8
A0998	20	1.27	008	017		18	48		49			" "	"		T#7 B#8

PHYSICAL PROPERTIES

MELT NO.	SLAB NO.	YIELD PSI X100	TENSILE PSI X100	% ELONG. IN 2"	% R.A.	BHN	IMPACTS V-Notch +10°F.				DESCRIPTION
C1946	[illegible]	614	914 848	26			56	55	52		1-190 x 86 x 6-1/4"
A0998	2	626	873 864	27			51	37	45		1-300 x 120 x 6-1/4"

Two Surface Drop Weight tests satisfactory at +10°F.

Plates heated 1625-1675°F., held 1 hr. per inch min. and water quenched to under 400°F. by holding in water for at least 3-1/2 minutes per inch of thickness., then tempered 1200-1250°F., held 1 hr. per inch min. and air cooled.
Tests from heat treated plates stress relieved by heating within a rate of 64°F per hr. to 1125-1175°F., held 50 hrs. and furnace cooled within a rate of [illegible] 80°F. per hr. to 600°F. and air cooled.
Second temper after gas cutting not higher than 1100°F. and held not longer than 1 hr. per inch of thickness.

Mill inspection by Chicago Bridge & Iron Co.

Affirmed and subscribed before me this ___ day of MAR 3 1967 19___

Chillip A. Romandino Jr.
Notary Public
My Commission Expires Apr. 1, 1968

OK HLW

We hereby certify the above figures are correct as contained in the records of the company.

SUPERVISOR-TESTING H. H. Kline

3-26

FORM # C1 8.9/62

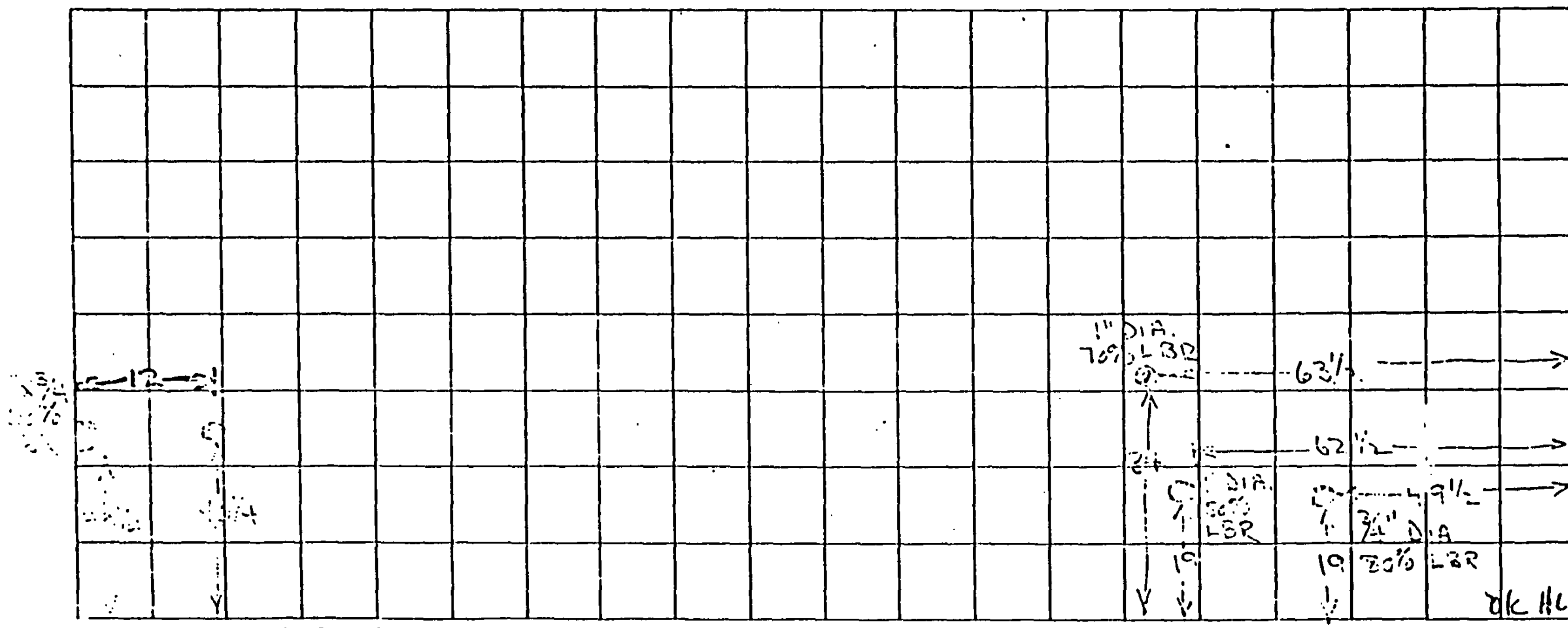
LUKENS STEEL COMPANY

INSPECTION DEPARTMENT

NON-DESTRUCTIVE TESTING REPORT

CORRECTED COPY   CORRECTED COPY

CUSTOMER	MILL ORDER NO.	TYPE TEST	DATE
CHICAGO BRIDGE + IRON CO. P.O. BOX 277 BIRMINGHAM, ALA.	1543-43211-1	REFLECTOSCOPE	11-21-66
	QUALITY MANG. MOLY NICKEL FIREBOX 80,000	SPECIFICATION ASME SEC. 3 CODE CASE 1335-2 ALT 2	
	CUSTOMER NO. 5624 SHEET 2	EQUIPMENT USED SPERRY UM721 REFLECTOSCOPE	
CONSIGNED TO CHICAGO BRIDGE + IRON CO. BOYLES, ALA.	SEARCH UNIT 2 1/4 MEG. 1 1/8 DIA. S.B.	AMPLITUDE AMPERAGE	COUPLANT SOAP + WATER
	TRANSDUCER SPERRY	GRID REF. 100% SEARCH	TYPE OF SURFACE BLASTED
	INSPECTORS NAME & QUALIFICATIONS E. MOHR	SIZE 1 - 300 x 120 x 6 1/4	
	WITNESSED BY	MELT & SLAB A0998-2	MARK



TOP END

OK HCW

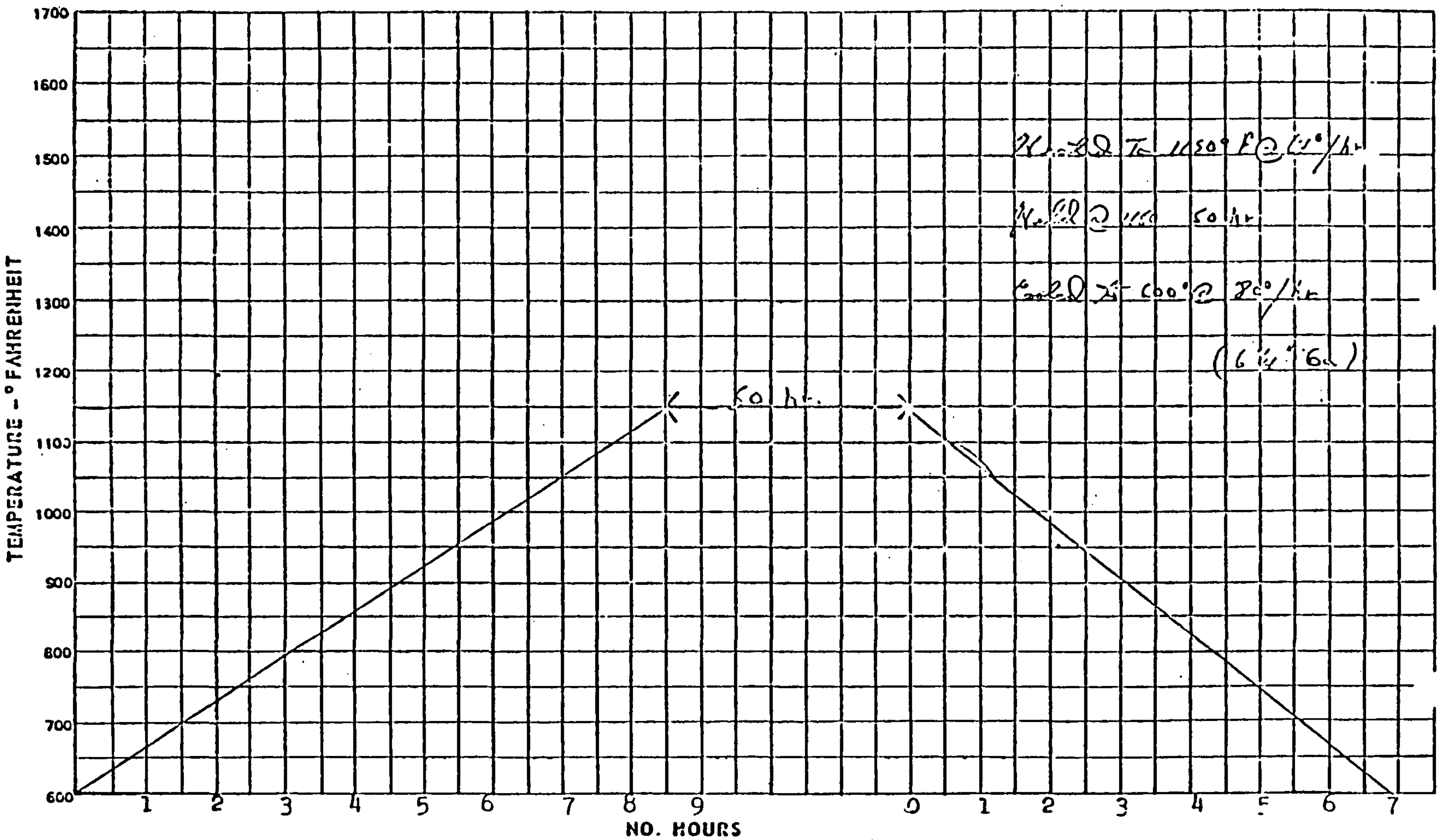
I HEREBY CERTIFY THAT THE ABOVE IS CORRECT TO THE BEST OF MY KNOWLEDGE AND BELIEF.

UT OK PER SPEC.

B. F. Reed

INSPECTION SUPERVISOR

HEAT TREATMENT RECORD
LUKENS STEEL COMPANY
COATESVILLE, PA.



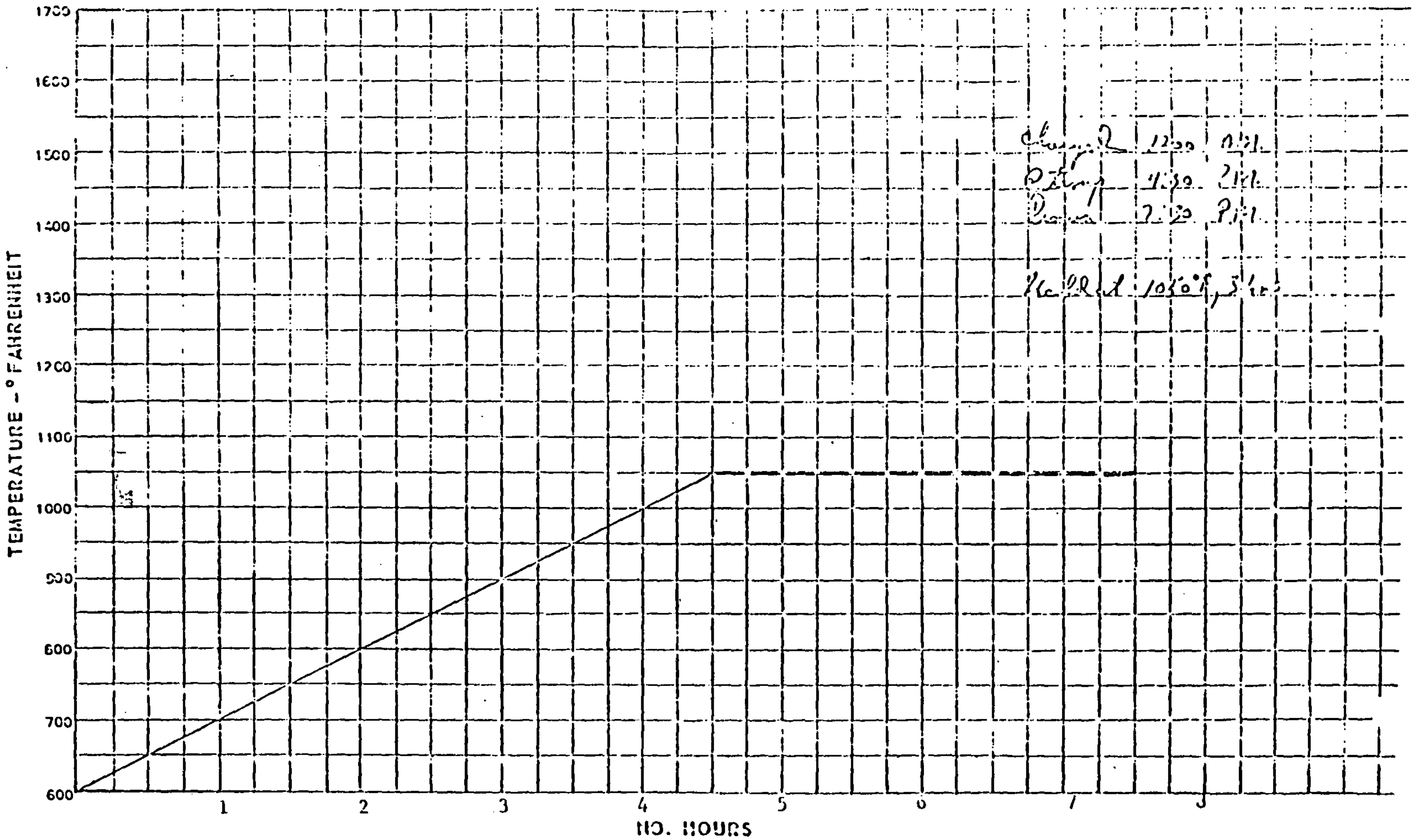
Order # 1543-43211-1   Contract 5624   Furnace B   Date 10-30-66

C1746-3
Heat No. A0997-2   Original Charts are available for customer verification

OK HCW

Supervisor of Testing

HEAT TREATMENT RECORD
LUKENS STEEL COMPANY
COATESVILLE, PA.



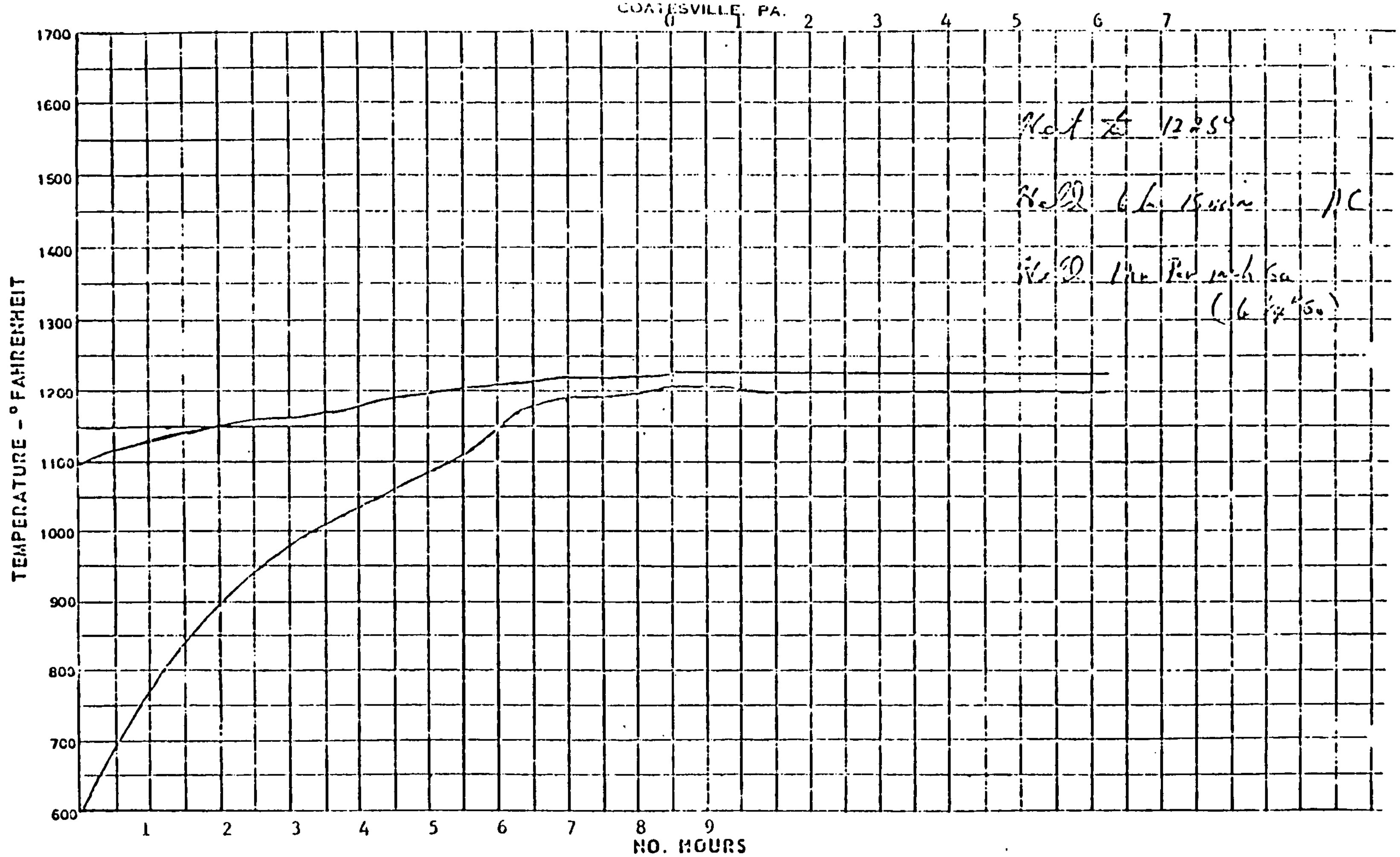
Order # 1543-43211-1 Contract 5624 Furnace #3 Date 11-6-66

A0998-2
Heat No. C1946-3 Original Charts are available for customer verification

ok

H. F. Kline
Supervisor of Testing

LUKENS STEEL COMPANY
COATESVILLE, PA.



Order # 1543-43211-1 Contract 5624 Furnace #6 Date 10-2-66

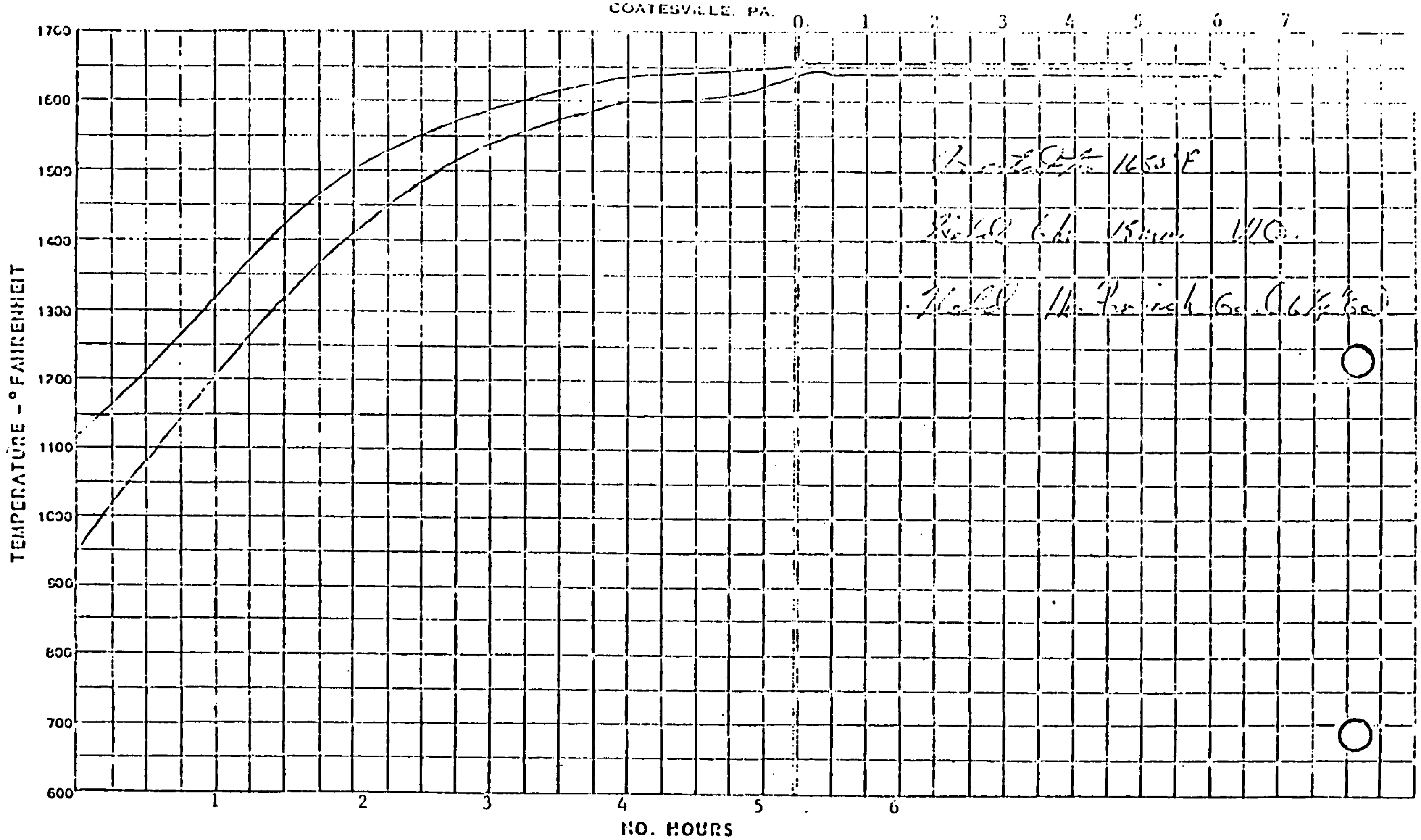
A0798-2
Heat No. C1946-3 Original Charts are available for customer verification

OK HI

L. H. Kline
Supervisor of Testing

LUKENS STEEL COMPANY

COATESVILLE, PA.



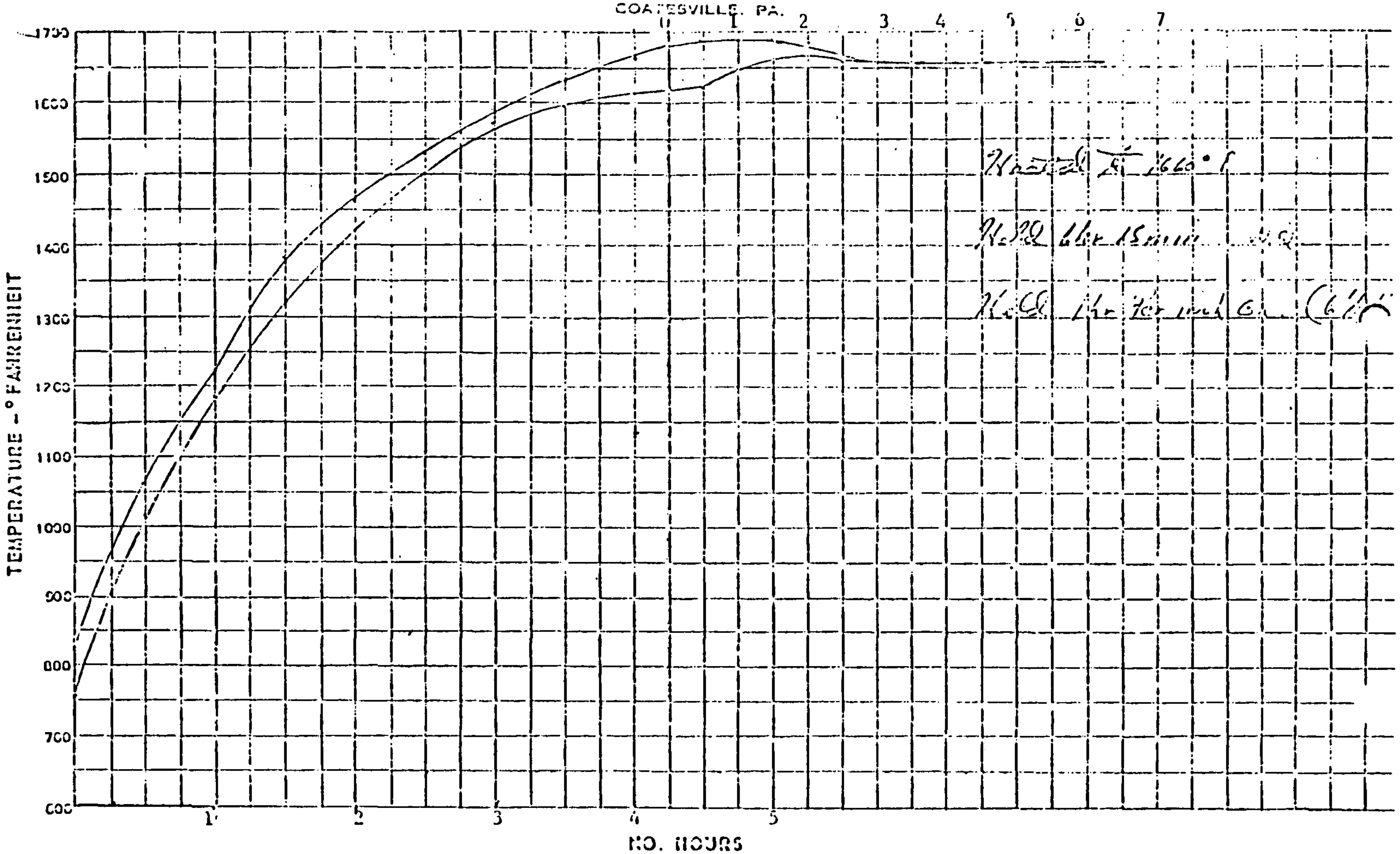
Order # 1543-4324-1 Contract 5604 Furnace #3 Date 10-19-66

Heat No. C1946-3 Original Charts are available for customer verification

ok Hcw

Supervisor of Testing

HEAT TREATMENT RECORD
LUKENS STEEL COMPANY
COATESVILLE, PA.



Order # 1513-43211-1 Contract 5624 Furnace #2 Date 10-19-66

Heat No. A0998-2 Original Charts are available for customer verification

OK HLW

L. H. Kline

EXHIBIT 4

SUMMARY STRESS REPORT

Summary Report

Monticello--NSP Reactor Vessel

CB&I Contract 9-5624

MONTICELLO

-339.1

2-1-1

General Electric P. O. No. 205-55582-I Reactor

CHICAGO BRIDGE & IRON COMPANY — OAK BROOK ENGINEERING

SUMMARY REPORT INDEX

MONTICELLO NUCLEAR REACTOR

* "S1" indicates a stress analysis and "T1" indicates a thermal analysis.

SUMMARY REPORT--INTRODUCTION

SUMMARY OF THE

MONTICELLO STRESS REPORT

The stress analysis for the Monticello Reactor Vessel has been performed in accordance with the General Electric Purchase Specification 21A1112, Rev. 5 and Section III of the ASME Code. The stress report has been certified by a registered professional engineer who is experienced in pressure vessel design.

The following paragraphs summarize the stress results for the various components of the Monticello Reactor Vessel. For each component, the calculated stress intensities for each stress category, primary membrane stress intensity, local membrane plus bending stress intensity and primary plus secondary stress intensity range, are compared with the appropriate Section III, ASME Code allowables. The specified fatigue cycles and Code allowable cycles are given wherever appropriate. This Summary Report is being submitted as required in Paragraph 6.8 of the General Electric Purchase Specification mentioned above.

SUMMARY OF STRESS ANALYSIS FOR MAIN CLOSURE FLANGES

The stress analysis for the main closure flanges and the studs was conducted in accordance with requirements of GE Design Specification No. 21A1112, Rev. 5, dated 9-30-68. Temperature distributions used in this analysis are presented in Section T1 of the stress report.

The minimum required stud cross-sectional area, per ASME Code, Section III, Article I-12, was found to be 1177.14 square inches (page I-S1-7). This was based on an allowable stress S_m = 36,325 psi at 575°F. The actual cross-sectional area, provided by 64 studs with 5-1/16 inch shank diameter and 7/16" extensiometer hole, is 1278.61 square inches. The average and maximum stud service stresses (per ASME III - N-416.1) were found to be critical during startup at 270 minutes into the transient, with their respective magnitudes being 47,929 psi and 89,824 psi (page I-S1-84). The average stud temperature at this time is 340°F. Allowable stresses at this temperature are 2 S_m = 79,280 psi for the average stress and 3 S_m = 118,920 psi for the maximum stress.

The stud fatigue anlaysis was performed in accordance with Par. N-416.2 of ASME Code, Section III. The peak stress intensity ranges were computed at the root of the thread using a fatigue strength reduction factor of 4. The cumulative usage factor was found to be 0.5637 which is well within the allowable of 1.0 (page I-S1-100).

The basic stress intensities in the main closure flanges and the adjacent top head and cylindrical shell per ASME Code, Section III, N-414, are as follows: the maximum primary membrane stress intensity in the top hemispherical head is due to preload plus pressure loading at 1250 psi and occurs 4.379 inches above the flange transition section. Its magnitude is 28,620 psi (page I-S1-64). Due to the influence of the head to flange discontinuity it is classified as a local primary membrane stress intensity. It is seen to be less than 1.1 S_m = 29,370 psi.

The maximum primary plus secondary stress intensity range occurs during the startup transient at the hemispherical head to top flange junction, and has a magnitude of 55,320 psi. The allowable stress intensity range in this case is 3 S_m = 80,100 psi.

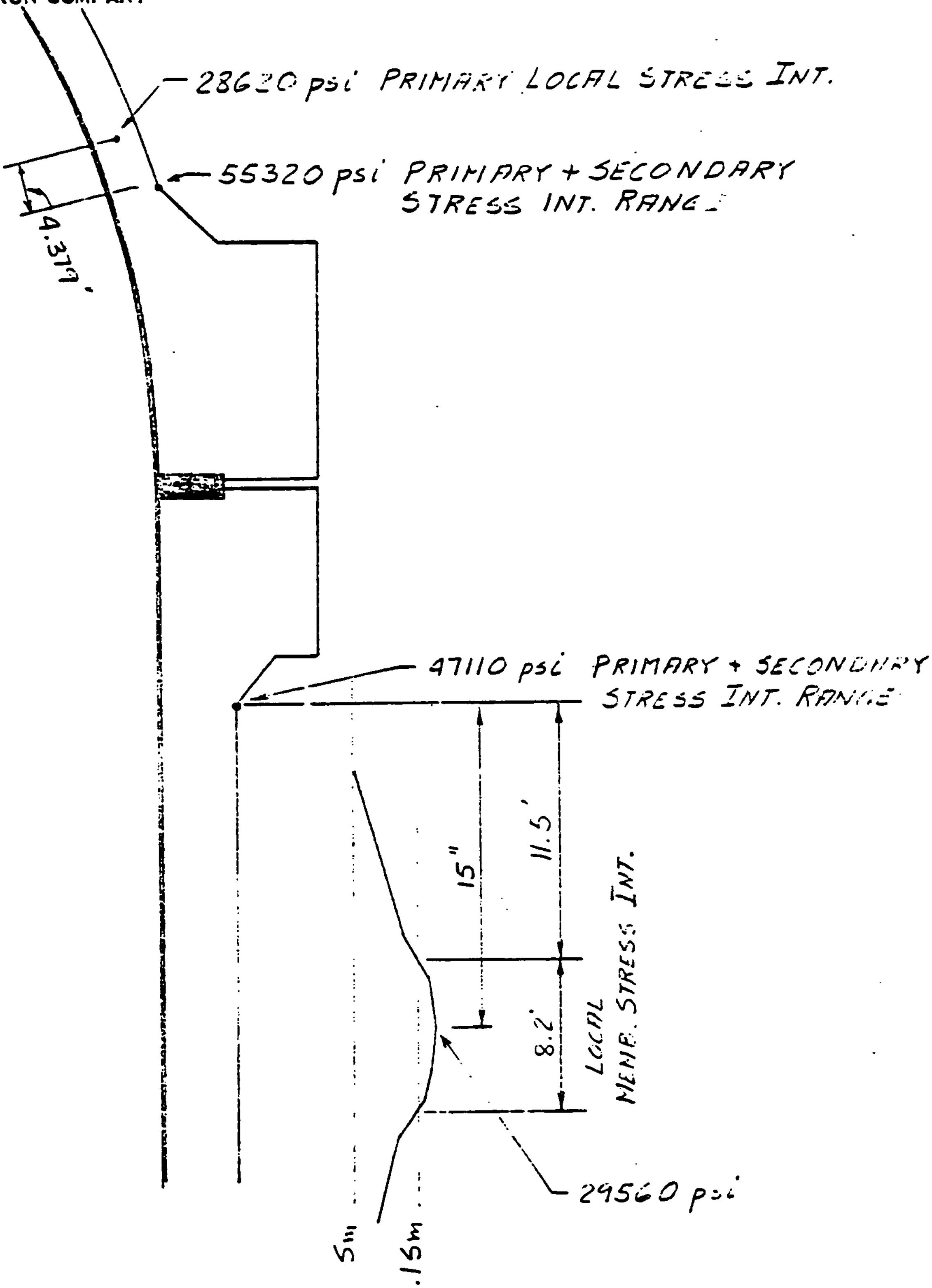
The maximum primary membrane stress intensity in the cylindrical shell below the shell flange is 29,560 psi (page I-S1-65). This stress intensity is due to the preload plus pressure loading at 1250 psi, and is located 15 inches below the cylinder to shell flange junction. As the width of the band in which 1.1 S_m = 29,370 psi is exceeded is 8.2 inches, and the allowable width is $.5\sqrt{Rt}$ = 11.746 inches, this stress intensity is classified as local. For the location of the above stress intensity band see the attached sketch. The allowable stress intensity for local primary membrane stress intensity is 1.5 S_m = 40,050 psi.

The maximum primary plus secondary stress intensity range in the shell flange is 47,110 psi (page I-S1-67). It occurs during the startup transient and is located on the outside of the shell flange to cylindrical shell junction. The allowable stress intensity range in this case is $3\ S_m = 80{,}100$ psi.

It was found that all the requirements of the ASME Code, Section III, Par. N-415.1 could be satisfied for the main closure flanges, and therefore no fatigue analysis of the same is required.

CHICAGO BRIDGE & IRON COMPANY

OAK BROOK ENGINEERING



MAIN CLOSURE FLANGES

MAX. STRESS INTENSITIES

Subject MONTICELLO REACTOR VESSEL Cont. 9-5424 Date 3/4/... By ... Sh. 6 of 34

Checked by____ Date____ Rev.No.____ Date____ Rev.No.____ Date____ Rev.No.____ Date____

SUMMARY OF STRESS ANALYSIS
FOR
SUPPORT SKIRT AND ITS JUNCTION TO BOTTOM HEAD

Using the data contained in the contract specifications and temperatures calculated in Section T2, the stress analysis has been done in Section S2.

The maximum value of seismic stress along the support skirt is 2623 psi. The maximum local membrane and bending primary stress intensity occurs at the inside point of the skirt-to-bottom head junction and has a value of 10,625 psi. The Code allowable at design temperature for the sum of all primary stresses is 1.5 S_m = 40,000 psi.

The value of the maximum range of primary plus secondary stress intensities, which also occurs at inside point of the junction, is 55,580 psi. The Code limits this range to 3 S_m = 80,000 psi.

The same point is also most critical from a fatigue standpoint. The conservatively calculated value of the fatigue usage factor at this point is 0.40.

SUMMARY OF RESULTS - STRESS ANALYSIS OF SHROUD SUPPORT

The static analysis of Subsection C of Section S3 indicates that all code requirements for the secondary membrane plus bending combined with local membrane, local and general primary membrane and also primary bending stress intensities, have been met. The maximum secondary membrane plus bending combined with local membrane stress intensities of 23,970 psi occurs at point 5 of the main shell (see page S3-57), and 26,099 psi occurs at point 17 of the shroud. Both of these stresses are below allowables of 3 S_m = 80,000 psi and 3 S_m = 70,000 psi respectively (see Figure 1).

Local membrane stress intensities of 15,555 psi at Section 7-8 and 15,575 psi at Section 17-18 are also within the allowable limits of 1.5 S_m = 40,000 psi and 1.5 S_m = 34,950 psi. Primary bending plus membrane and general primary membrane stress intensities are 26,740 psi at point b and 26,585 psi at Section a-b on the main shell which are below the allowable of 1.5 S_m = 40,000 psi and S_m = 26,700 psi. This also holds for internals with maximum primary membrane stress = 7,910 psi at point c and primary general membrane stress = 7,750 psi at Section c-d for Inconel material for which allowables are 34,950 psi and 23,300 psi respectively (see Figure 1).

Subsection C of Section S3 also shows that the stilts which support the shroud will not buckle under the most critical compressive load.

Stress intensity calculations of Subsection E of Section S3 show that maximum range of secondary membrane plus bending stress intensity for carbon steel is 62,100 psi at point 13, which is less than the allowable of 3 S_m = 80,000 psi, and Inconel material for the internals is 58,924 psi at point 30, also within the allowable of 3 S_m = 70,000 psi (see Figure 2).

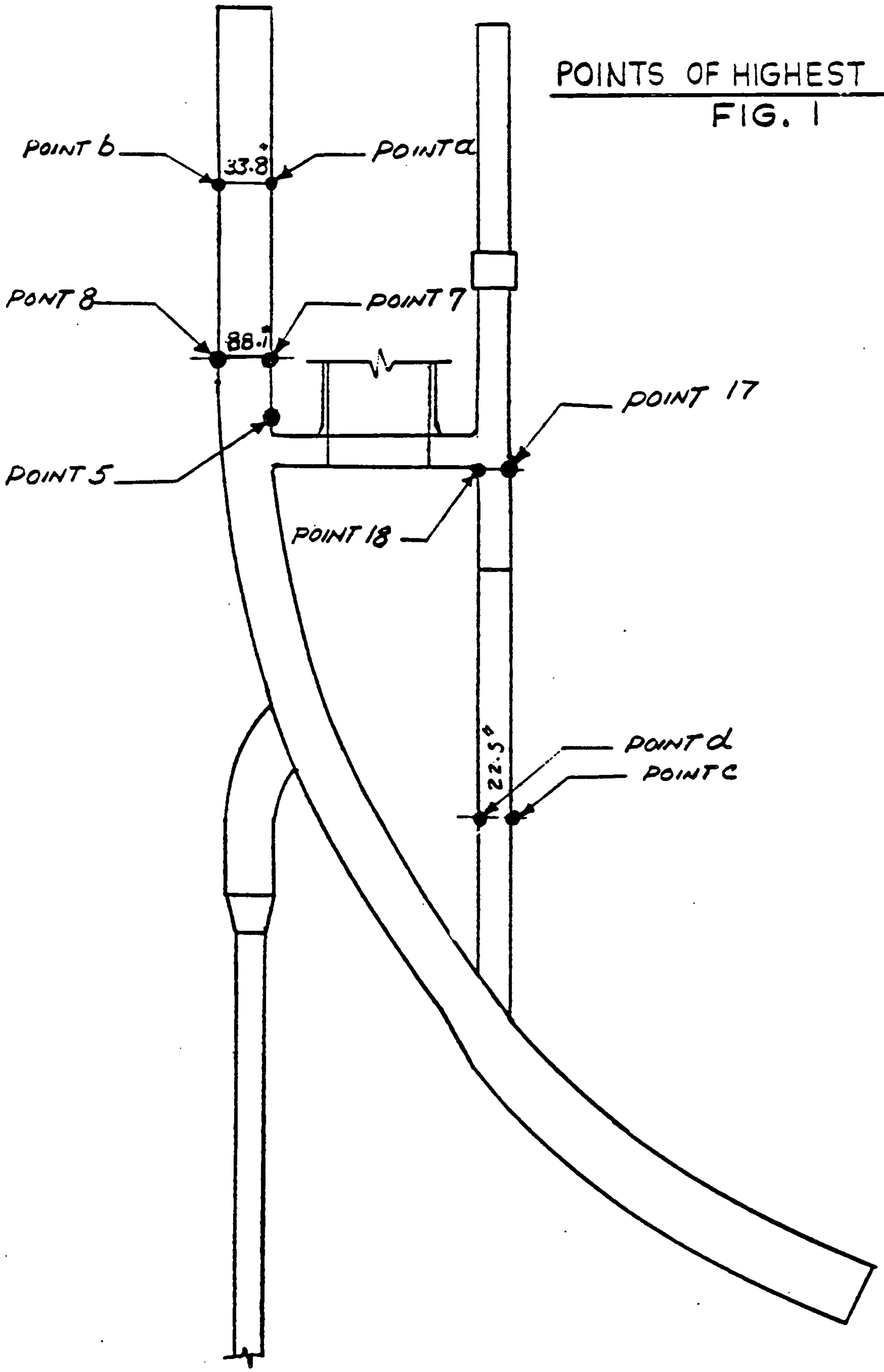
Stress analysis of the jet pump baffle plate was performed at the junctions to the main shell and shroud support. Results are listed under Subsection F for static loading and transients considered. The results in the static analysis show that local membrane stress intensity is 17,327 psi at Section 3-4 and secondary membrane plus bending combined with local membrane stress intensity is 19,229 psi at point 3 within the allowables of 1.5 S_m = 34,950 psi and 3 S_m = 70,000 psi respectively. Results of loading plus transients stress analysis show maximum range of stress intensity of 63,656 psi at point 3 which is also below the allowable of 3 S_m = 70,000 psi (see Figure 2).

Fatigue analysis performed under Subsection G shows a permissible number of 4000 cycles and the usage factor of .064 for point 7 based on stress results of Subsection E and 20,000 cycles and the usage factor of .012 for point 3 based on Subsection F (see Figure 2).

CHICAGO BRIDGE & IRON COMPANY

OAK BROOK ENGINEERING
SPECIAL STRUCTURES DESIGN

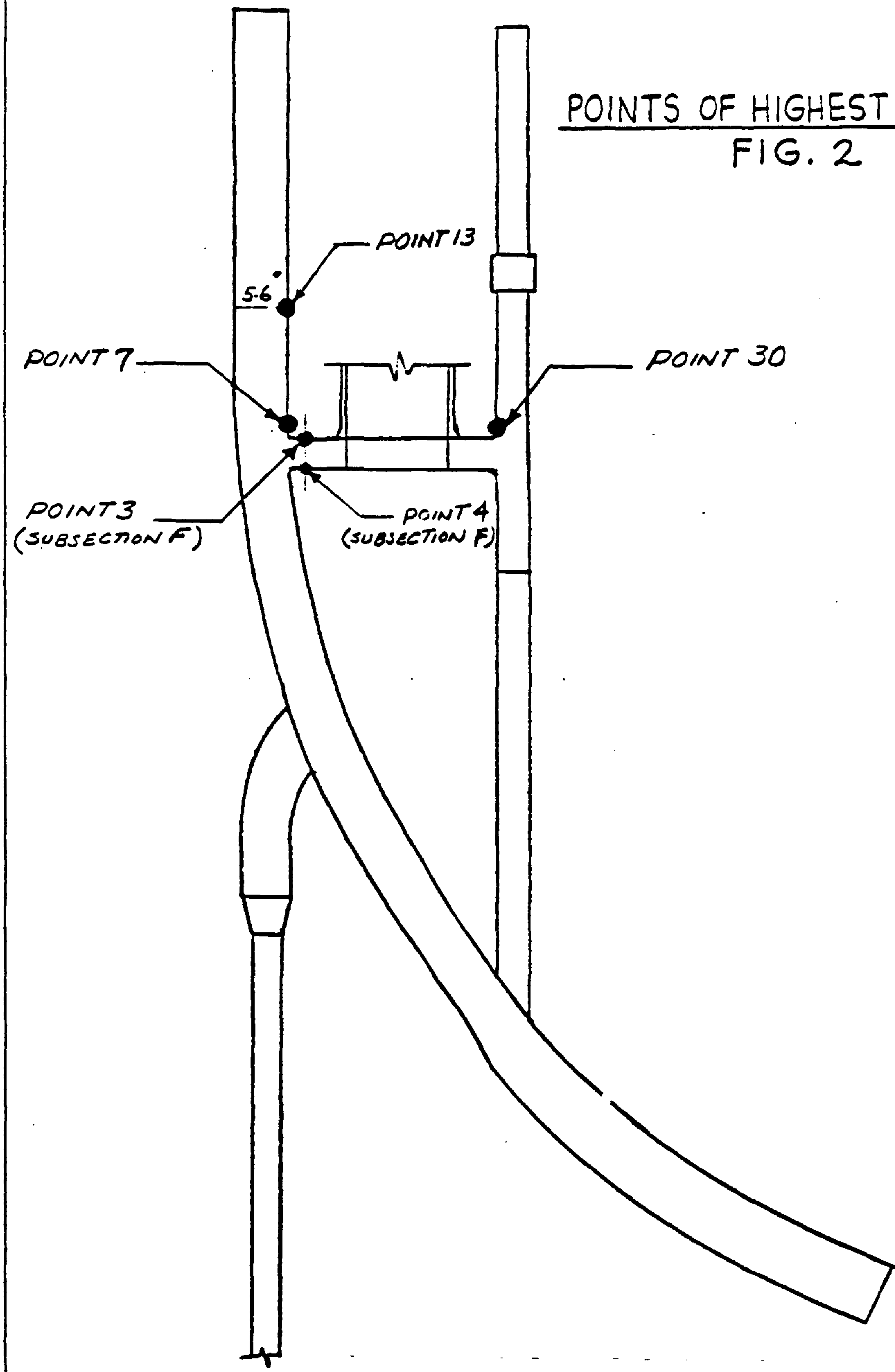
POINTS OF HIGHEST STRESSES
FIG. 1



CHICAGO BRIDGE & IRON COMPANY

OAK BROOK ENGINEERING
SPECIAL STRUCTURES DESIGN

POINTS OF HIGHEST STRESSES
FIG. 2



SUMMARY OF STRESS ANALYSIS

FOR FEEDWATER NOZZLE

Using the loadings contained in the contract specification and temperatures calculated in Section T4, the stress analysis has been performed in accordance with Article 4 of Section III of the ASME Code.

The area replacement requirements of Article 4 have been satisfied. The calculated maximum general membrane stress intensity for the safe end is 18,200 psi (page S4-10) compared to the allowable, at 575°F, of 18,200 psi. For the nozzle forging, the calculated maximum general primary membrane stress intensity is 14,218 psi compared to the allowable of 26,700 psi.

The maximum local membrane and bending stress intensity due to design pressure plus nozzle loads is 22,580 psi (page S4-10) at section AA on the attached sketch. The allowable stress intensity is 1.5 S_m = 27,300 psi.

The maximum ranges of primary plus secondary stress intensity are 26,540 psi on the inside of section DD and 59,600 psi on the inside of section CC for the safe end and nozzle forging respectively. (See pages S4-35 and S4-33.) The Code allowable ranges are 56,040 for the safe end material and 80,100 psi for the forging.

The allowable number of fatigue stress cycles is 1760 versus a specified number of 1500.

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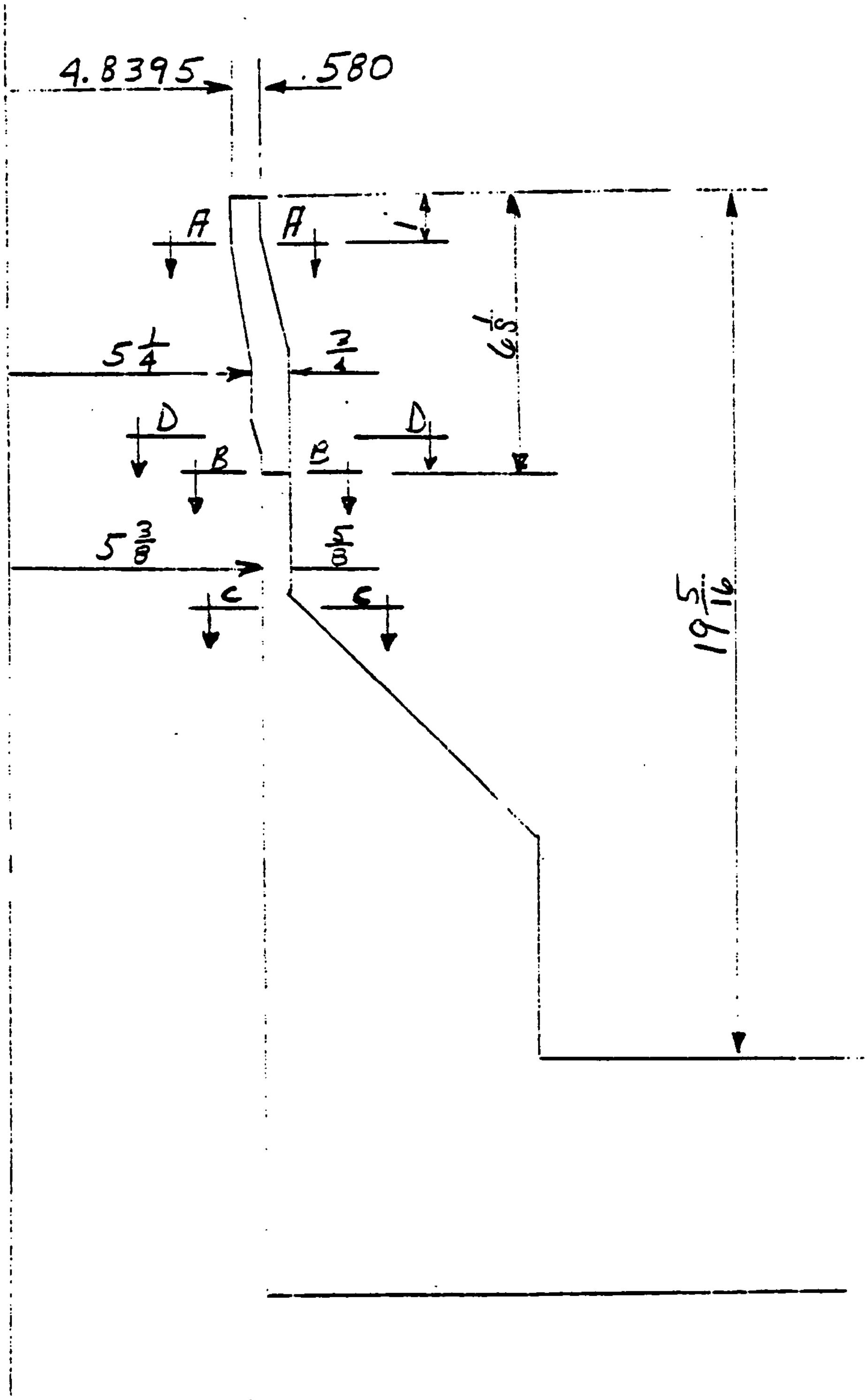
OAK BROOK ENGINEERING



FEEDWATER NOZZLE

N4A THRU N4D

Subject MONTICELLO REACTOR VESSEL Cont. 9-5624 Date 3/4/69 By JH Sht 13 of 34

GO 6408 Checked by ____ Date ____ Rev.No. ____ Date ____ Rev.No. ____ Date ____ Rev.No. ____ Date ____

SUMMARY OF STRESS ANALYSIS
CRD PENETRATIONS

The maximum primary plus secondary stress intensity in the stainless steel housing is 38,408 psi compared to an allowable of 3 S_m (= 52,800 psi), at point 1. The maximum value for the Inconel stub tube is 58,351 psi at point 2 against an allowable of 3 S_m (= 60,000 psi).

The maximum alternating stress intensity occurs at point 3. This value is 79,634 psi. The allowable number of cycles from the applicable design fatigue curve is 2900 against 370 specified cycles.

The points referred to above are shown in the sketch on the following page. The sketch shows an outermost penetration which is found to be more critical than the center penetration.

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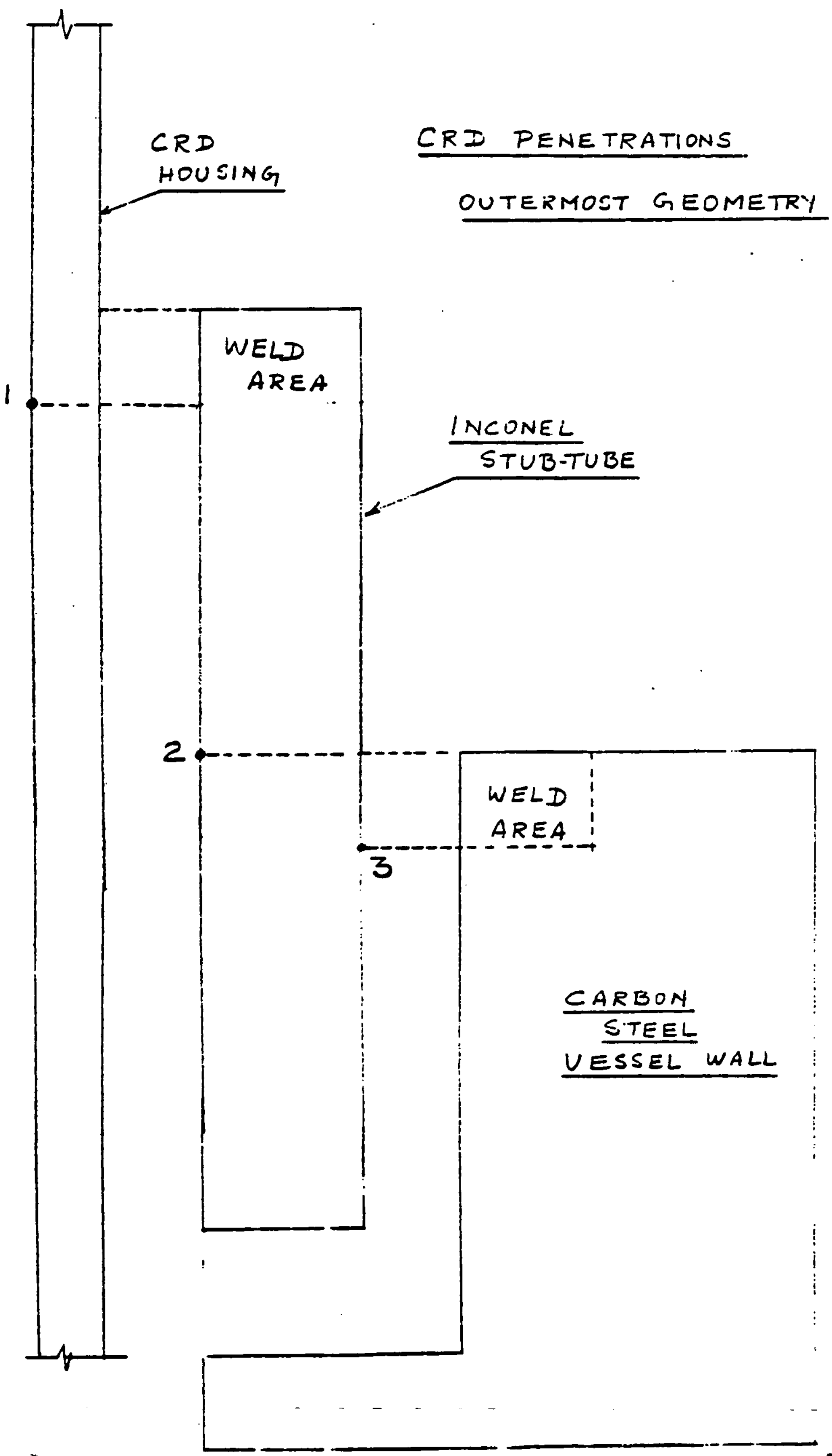

Subject MONTICELLO REACTOR PROJECT Cont. 9-5624 Date___ By MCM Sht 15 of 34

GO 6408 Checked by___ Date___ Rev.No.___ Date___ Rev.No.___ Date___ Rev.No.___ Date___

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SUMMARY OF STRESS ANALYSIS

3" CRDHSR NOZZLE

In the safe end area, the maximum primary plus secondary stress intensity of 44,320 psi occurs at point 3, against an allowable of 48,000 psi at design temperature.

In the nozzle forging, the nozzle vessel junction (point 19) is the highest stressed point. Based on the stress index method, the maximum pressure stress intensity is 88,100 psi. To this is added the thermal stress intensity at steady state, which is 38,841 psi, giving a peak stress intensity range of 126,951 psi and an alternating stress amplitude of 63,475 psi, which gives an allowable number of cycles of 2000 against an expected 782 cycles, based on the applicable design fatigue curve.

The points referred to above are shown in the sketch on the following page.

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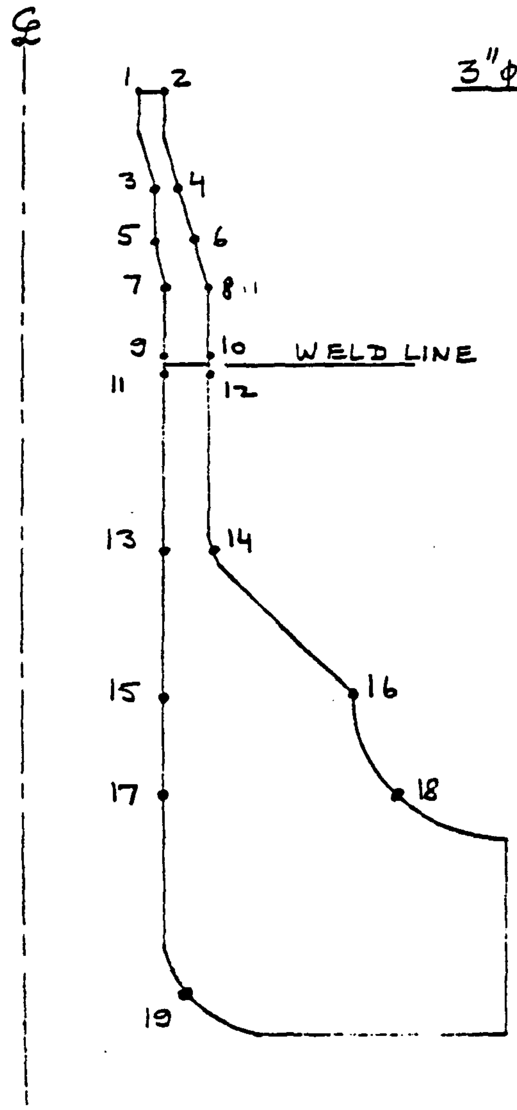
3"φ CRDHSR NOZZLE



SUMMARY OF STRESS ANALYSIS
for
CORE SPRAY NOZZLE

Using the data contained in the contract specifications and temperatures calculated in Section T7, the stress analysis has been done in Section S7.

The calculated maximum general membrane primary stress intensity, for the safe end, is 14,050 psi (page S7-7) compared to the allowable, at 575°F design temprature, of 23,300 psi. For the nozzle, the calculated maximum general membrane primary stress intensity is 12,550 psi (page S7-8) and the allowable at design temperature is 26,700 psi.

The maximum local membrane and bending primary stress intensities are 24,783 psi, 2,656 psi, and 11,123 psi for the safe end, sleeve and nozzle respectively,(page S7-86). The allowables for corresponding materials in the same order are 35,000 psi, 23,700 psi and 40,000 psi.

The maximum range of primary plus secondary stress intensities are 28,262 psi, 29,445 psi and 8,157 psi at points 8, 22 and 31 respectively, (page S7-92). These points are located on the safe end, sleeve,and nozzle, in that order; with respective allowables of 70,000 psi, 47,400 psi and 80,000 psi.

The most critical point from the fatigue standpoint is point 11. The conservatively calculated value of the fatigue usage factor at this point is 0.52.

(Points referred to above are shown on the sketch of the following page.)

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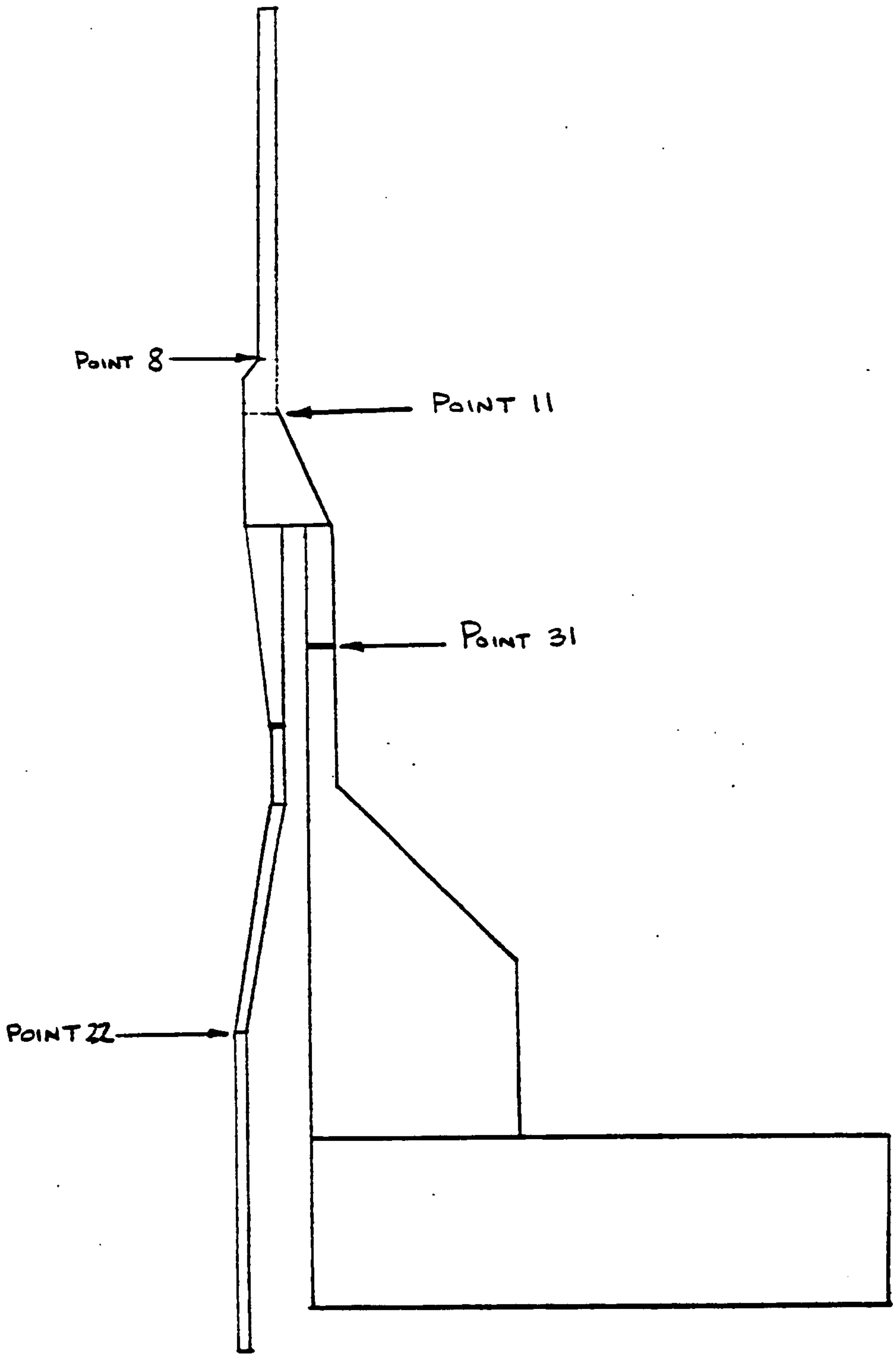


CORE SPRAY NOZZLE

SUMMARY OF STRESS ANALYSIS
for
RECIRCULATION INLET NOZZLE

Using the data contained in the contract specifications and temperatures calculated in Section T8, the stress analysis has been done in Section S8.

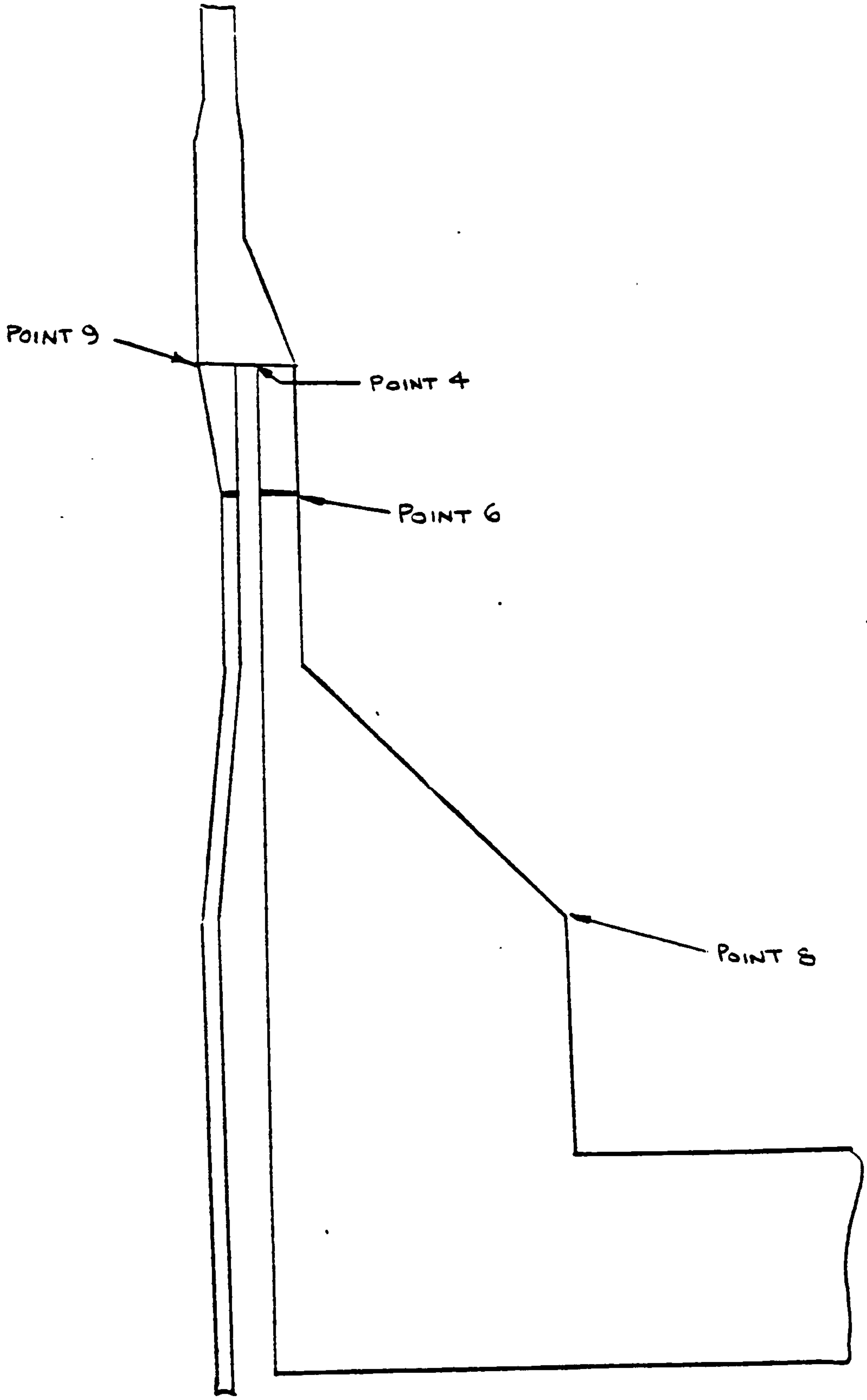
The calculated maximum general membrane primary stress intensity, for the safe end, is 12,900 psi (page S8-4) compared to the allowable, at 575°F design temperature, of 15,800 psi. For the nozzle, the calculated maximum general membrane primary stress intensity is 16,600 psi (page S8-5) and the allowable at design temperature is 26,700 psi.

The maximum local membrane and bending primary stress intensities are 17,107 psi (page S8-9) and 23,488 psi (page S8-11 for the safe end and nozzle respectively. The allowables for corresponding materials in the same order are 23,700 psi and 40,000 psi.

The maximum range of primary plus secondary stress intensities are 33,670 psi (page S8-30), 47,830 psi (page S8-33) and 43,550 psi (page S8-31) at points 4, 9 and 6 respectively. These points are located on the safe end, sleeve and nozzle, in that order; with respective allowables of 47,900 psi, 47,900 psi and 80,000 psi.

The most critical point from the fatigue standpoint is point 8. The calculated value of the fatigue usage factor at this point is approximately .003.

(Points referred to above are shown on the sketch of the following page.)



RECIRCULATION INLET NOZZLE

SUMMARY OF STRESS ANALYSIS FOR RECIRCULATION OUTLET

Using the loadings contained in the contract specification and temperatures calculated in Section T9, the stress analysis has been performed in accordance with Article 4 of Section III of the ASME Code.

The area replacement requirements of Article 4 have been satisfied. The calculated maximum general membrane stress intensity for the safe end is 13,806 psi (page S9-36) compared to the allowable, at 575°F, of 15,800 psi. For the nozzle forging, the calculated maximum general primary membrane stress intensity is 12,261 psi compared to the allowable of 26,700 psi.

The maximum local membrane and bending stress intensity due to design pressure plus nozzle loads is 14,777 psi at section AA on the attached sketch (page S9-37). The allowable stress intensity is 1.5 S_m = 23,700 psi.

The maximum ranges of primary plus secondary stress intensity are 26,540 psi on the inside of section BB and 36,700 psi on the inside of the same section at the safe end-nozzle forging junction. See page S9-19 of the report. The Code allowable ranges are 47,400 for the safe end material and 80,100 psi for the forging.

The Code allowable number of fatigue stress cycles for the maximum stress amplitude is 41,720 compared with the 400 cycles specified.

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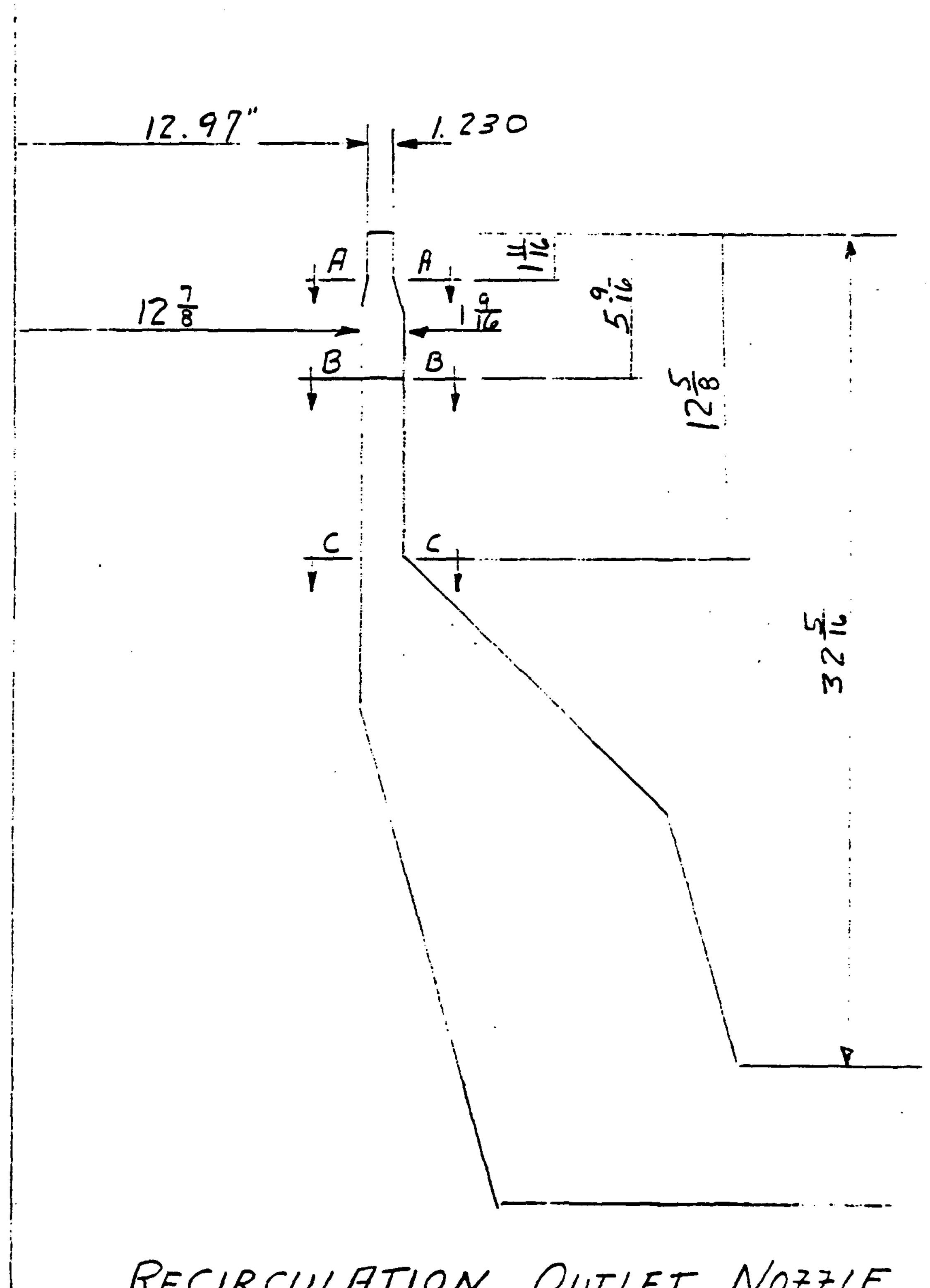

RECIRCULATION OUTLET NOZZLE

N1A & N1B

Subject________ Cont.______ Date 3/4/67 By JH Sht 23 of 34

6408 Checked by______ Date______ Rev.No.______ Date______ Rev.No.______ Date______ Rev.No.______ Date______

SUMMARY OF STRESS ANALYSIS
18" STEAM OUTLET NOZZLE

The maximum primary plus secondary stress intensity in the safe end is 11,924 psi at point 1 against an allowable of 57,450 psi (3 S_m at design temperature).

In the nozzle forging, the nozzle-vessel junction is the highest stressed point (point 13). Based on the stress index method, the maximum pressure stress intensity is 88,100 psi. To this is added the maximum thermal stress intensity of 19,592 psi and the additional stress intensity due to the pipe reactions at the point which is 10,919 psi, giving a total peak stress intensity of 118,621 psi and an alternating stress amplitude S_{alt} of 59,310 psi. This gives an allowable number of cycles of 2500 which is more than the expected 532 cycles.

The points referred to above are shown in the sketch on the following page.

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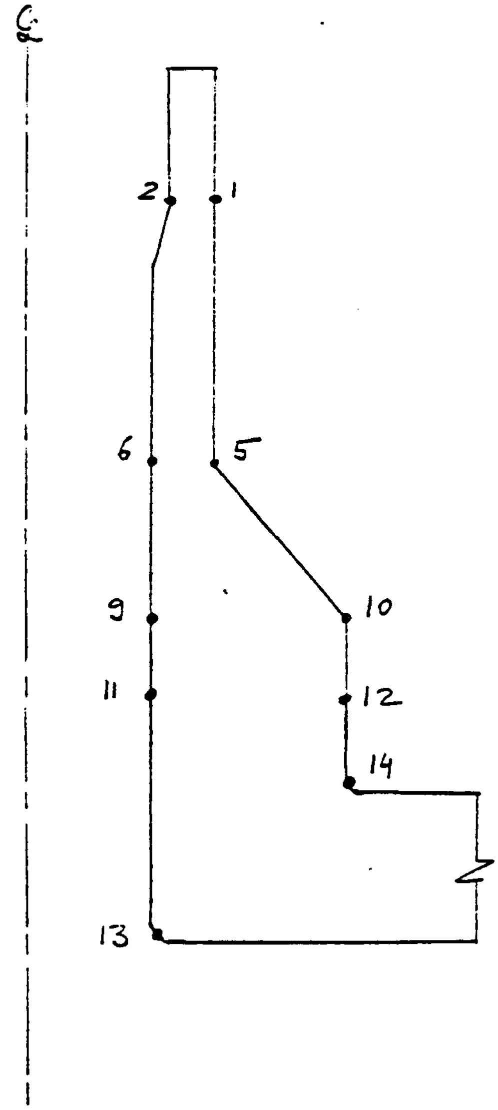
18" ϕ STEAM OUTLET NOZZLE



SUMMARY OF STRESS ANALYSES
for
CORE DIFFERENTIAL PRESSURE AND LIQUID CONTROL NOZZLE,
HEAD COOLING SPRAY AND INSTRUMENTATION NOZZLES,
VENT NOZZLE,
INSTRUMENTATION NOZZLES,
JET PUMP INSTRUMENTATION NOZZLES,
DRAIN NOZZLE,
HIGH PRESSURE SEAL LEAK DETECTOR NOZZLE
and
LOW PRESSURE SEAL LEAK DETECTOR NOZZLE

The maximum primary membrane stress intensity for the core differential pressure and liquid control nozzle is 6076 psi (page S11-6), compared to the allowable, 15,800 psi. This nozzle has been exempted from fatigue analysis in accordance with the rules of Par. N-415.1 of Section III, ASME Code.

The maximum primary membrane stress intensity for the head cooling spray and instrumentation nozzles is 2849 psi (page S12-7), compared to the allowable, 15,800 psi. This nozzle has been exempted from fatigue analysis in accordance with the rules of Par. N-415.1 of Section III, ASME Code.

The maximum primary membrane stress intensity for the vent nozzle is 2501 psi (page S13-6), compared to the allowable, 15,800 psi. This nozzle has been exempted from fatigue analysis in accordance with the rules of Par. N-415.1 of Section III, ASME Code.

The maximum primary membrane stress intensity for the jet pump instrumentation nozzles is 10,489 psi (page S15-6), compared to the allowable, 15,800 psi. This nozzle has been exempted from fatigue analysis in accordance with the rules of Par. N-415.1 of Section III, ASME Code.

The maximum primary membrane stress intensity for the instrumentation nozzles is 5796 psi (page S14-6), compared to the allowable, 15,800 psi. This nozzle has been exempted from fatigue analysis in accordance with the rules of Par. N-415.1 of Section III, ASME Code.

SUMMARY OF STRESS ANALYSIS FOR REFUELING BELLOWS

Using the data contained in the contract specifications and the temperatures calculated in Section T16, following is a summary of the stress analysis which is found in Section S16.

The calculated maximum general membrane primary stress intensity for the refueling bellow skirt is 3547 psi occuring during refueling at a point midway on piece #3. This is compared to the allowable at 70°F of 23,300 psi. (See Page I-S16-A18 of the Stress Report.)

The maximum local membrane and bending stress intensity is 10,310 psi occuring at the inside face of part #2 at the junction to part #1. This occurs during refueling. This is compared to the allowable stress intensity of 34,950 psi at 70°F. (See Table 1, Page I-S16-1 of Section S16.) The maximum range of primary plus secondary stress intensity is 51,734 psi and occurs in the cooldown-steady state cycle at the inside face of the junction of part #3 and part #2. The maximum allowable stress intensity at 545°F is 59,070 psi. (See Pages I-S16-1 and I-S16-10.)

The most critical point from a fatigue standpoint is at the junction of part #2 and #3 during the cooldown-steady state cycle. The fatigue usage factor at this point is .67. (See Page I-S16-2 of Section S16.)

(Points referred to above are shown on the sketch on the following page.)

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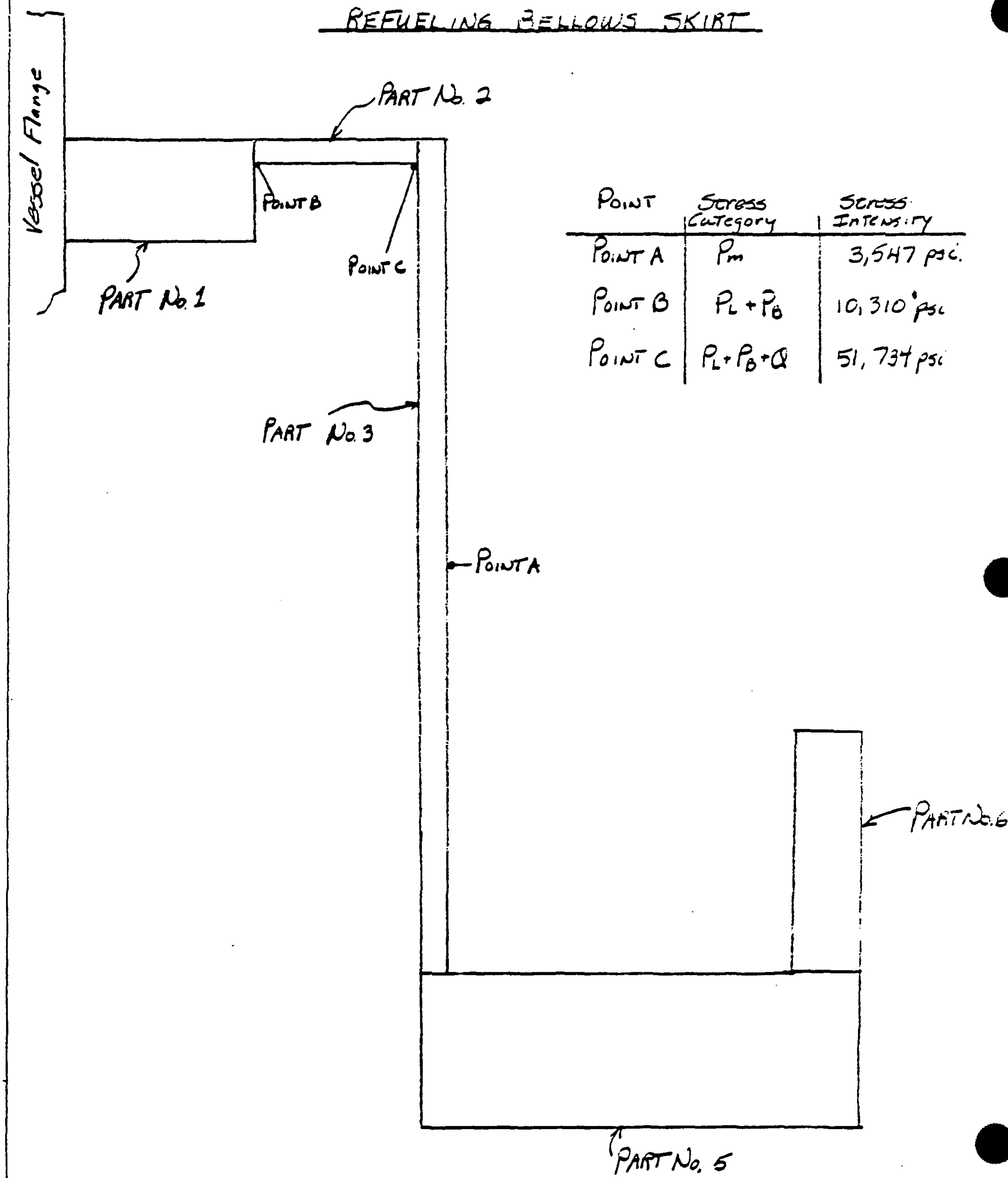
OAK BROOK ENGINEERING
SPECIAL STRUCTURES DESIGN

REFUELING BELLOWS SKIRT



POINT	Stress Category	Stress Intensity
POINT A	P_m	3,547 psi.
POINT B	$P_L + P_B$	10,310* psi
POINT C	$P_L + P_B + Q$	51,734 psi

SUMMARY OF STRESS ANALYSIS FOR
STABILIZER BRACKETS

The stabilizer brackets were analyzed for two loading conditions per GE Specification Drawing 886D482, Sheet 8. For loading condition #1 the bracket stresses were limited to allowable stresses per ASME Code, Section III. For loading condition #2 the bracket stresses were limited to the yield strength of the material.

The bracket design stresses and the corresponding allowable stresses are as follows:

LOADING CASE 1

Actual Maximum Stresses

Pure Shear Stress at Pin Hole	= 15,238 psi
Bearing Stress at Pin Hole	= 21,642 psi
Maximum Stress Intensity At Face of Shell	= 14,593 psi

Allowable Stresses

Pure Shear Stress	= 16,020 psi
Bearing Stress	= 42,300 psi
Maximum Stress Intensity	= 26,700 psi

LOADING CASE 2

Actual Maximum Stresses

Pure Shear Stress at Pin Hole = 19,551 psi

Bearing Stress at Pin Hole = 27,767 psi

Maximum Stress Intensity At Face of Shell = 26,854 psi

Allowable Stresses

Pure Shear Stress = 21,150 psi

Bearing Stress = 42,300 psi

Maximum Stress Intensity = 42,300 psi

SUMMARY OF STRESS ANALYSIS

FOR BRACKETS

Brackets were analyzed for loadings specified on GE Drawing 886D482, Sheet 7, Rev. 5. All brackets, except stabilizer brackets and steam dryer supports*, are included in this section.

The brackets are subject to primary membrane and bending stresses for which the allowable stress intensity is 1.5 S_m in accordance with Fig. N-414, Section III of the ASME Code.

The maximum stress intensities for the various brackets are as follows:

BRACKET	STRESS INTENSITY
Core Spray	10,007 psi
Guide Rod	18,982 psi
Feedwater Sparger	314 psi
Dryer Hold Down	9,052 psi
Shell Insulation Support	2,500 psi
Head Insulation Support	1,590 psi
Upper Surveillance Bracket	8,350 psi
Lower Surveillance Bracket	5,078 psi

The allowable stress intensity for all brackets, except the guide rod brackets and the head insulation supports is 24,060 psi at 545°F. The allowable stress intensity for the guide rod brackets is 30,000 psi at 120°F and the head insulation supports 28,725 psi at 575°F.

* The steam dryer supports have been reanalyzed for the replacement steam dryer. (Reference EC 14214)

SUMMARY OF STRESS ANALYSIS FOR TOP HEAD AND CYLINDRICAL SHELL

In this section the maximum stress intensities in the top head and cylindrical shell due to combined loadings were computed. The loadings considered were: stud preload, internal pressure, dead weight of vessel and contents, insulation weight, horizontal and vertical seismic forces, horizontal jet reactions, stabilizer rod reactions, local bracket and nozzle reactions, refueling bellows support loads, and the thermal loads.

The maximum stress intensities and their locations were found to be as follows: the maximum general primary membrane stress intensity occurs in that portion of the cylindrical shell which is removed from gross structural discontinuities. Its magnitude is 26,375 psi which is within the allowable value of 1 S_m = 26,700 psi. The maximum local membrane stress intensity of 29,610 psi occurs at 15 inches below the bottom of the shell flange hub. This stress intensity was found to be local in extent and is less than the allowable value of 1.5 S_m = 40,050 psi.

The maximum range of stress intensity for primary plus secondary stresses has a magnitude of 55,320 psi which is well within the allowable of 3 S_m = 80,100 psi. The location of this stress intensity is at the top of the hub of the head flange.

SUMMARY OF STRESS ANALYSIS FOR
DRAIN NOZZLE

The Code area replacement requirements for the drain nozzle have been satisfied.

The maximum primary membrane stress intensity is 6716 psi versus the Code allowable of 18,200 psi.

EXHIBIT 5

VESSEL FABRICATION AND ASSEMBLY REPORT

MONTICELLO
GENERAL ELECTRIC CO.
APED - SAN JOSE

VPF# 1811-356-1
EP# 2-1-1

IV. VESSEL FABRICATION AND ASSEMBLY

4.1 DIVISION OF WORK

A significant portion of the vessel fabrication was performed in the shop, just as would be done for a shop fabricated vessel. This work was in accordance with the ASME Code and G.E. fabrication and quality control requirements. The balance of the fabrication and assembly at the site was performed, utilizing proven techniques and equipment, without any compromise in the design, quality, or functional requirements of the vessel.

A typical site assembly area is shown in Figure IV-1 and an artist's rendering of the completed composite reactor and containment vessels is shown in Figure IV-2.

4.2 SHOP FABRICATION AND SUBASSEMBLY WORK

As much fabrication and subassembly work as possible was performed at CB&I's Birmingham, Alabama, and Greenville, Pennsylvania, manufacturing plants. The overall job economics favored this approach because of the convenience of overhead handling equipment, utilization of the existing shop labor pool and facilities for machining, heat treatment, etc. Restriction on shipping dimensions (not weight) was the determining factor in considering how much of the vessel assembly work could be performed prior to shipment.

An effort was made to clear completed shell rings 18 feet diameter by 10 feet 11-1/2 inches long and weighing 140,000 pounds. Although these rings could be barged to Minneapolis, the interconnecting railroad (Minneapolis, Northfield and Southern Railway) could not move the shipment from Port Cargill to the Great Northern Cedar Lake yard interchange. The Great Northern services the Monticello area. Overland truck handling clearance checks were also unsuccessful in finding an open route to the Great Northern Railroad; therefore, half ring sections were shipped from the shop. Figure IV-3 shows the shop assembled pieces for the Monticello reactor vessel.

A 17-foot diameter support skirt extension with leveling devices attached was shipped in one piece to the site. It joined the stub skirt on the vessel bottom head to the long skirt constructed with the drywell, as shown in Figure IV-2.

A cold forming procedure was utilized to press the bottom head, shell, and top head plates. All plate material was detailed to the maximum length and width dimensions that could be delivered from eastern mills and properly handled by the fabricating facility. The shell plates were purchased in the quenched and tempered condition and cold formed utilizing approved procedures.

Before starting fabrication, all plates were inspected for size, thickness, surface condition and the mill stamps properly identified. Ultrasonic testing of material was done by trained and qualified personnel in accordance with Code specifications. Certified mill test reports and all quality control measures were reviewed by CB&I engineers to assure compliance with material specifications.

After the plates were marked and flame cut to approximate size, they were pressed to shape on a 6,000-ton hydraulic press, designed by CB&I. Any minor deviation from curvature tolerances found in checking with box templates and sweeps were corrected by sizing the plates on the press. Each plate was then marked and cut to size and edges beveled with semi-automatic cutting torches. To insure proper dimensions and alignment, shop assembled weldments were fit-up and match-marked prior to shipment to the jobsite for assembly and welding together.

The bottom head was shipped in two sections consisting of (1) the knuckle course of plates with the stub skirt attached and (2) the dollar plate assembly. The dollar plate assembly was predrilled in the shop to accommodate the 121 control rod drive sleeves. The initial holes were drilled to approximately 5 inches in diameter. These holes are large enough to accommodate a boring bar cutting assembly that was used in place for the final boring of the sleeves at the site. Because of the availability of machining equipment, this assembly and predrilling work was performed at CB&I's Greenville, Pennsylvania, plant. The final drilling of the holes was performed in place at the site.

The bottom head knuckle course shop weldment was positioned and two overlay weld metal build-ups were applied (see Figure IV-4) in the two areas where the shroud support was welded to the bottom head. These weld build-ups were shop machined to the contours shown in Figure IV-4.

The Monticello vessel shell was made up of four rings, approximately 11 feet wide. Each ring was made from two formed plates. The half ring sections were temporarily welded together and placed on a roller bed. The ring was preheated and the overlay weld metal deposited with automatic equipment similar to that shown in Figure IV-5. All shell fittings were shop installed. Postweld heat treatment was performed and inspection of the overlay weld deposit and insert seams was made after cool-down.

The shell and head flanges were shipped directly to the site as rough machined, non-drilled, seamless forged rings from the Ladish Company plant in Cudahy, Wisconsin. The weld ends were prepared at the forge works (Ladish) for fit-up and welding to the adjacent No. 4 shell ring and top head weldment. This top head assembly was shipped in one piece. It was welded together from six knuckle plates and a one-piece dollar plate assembly, as shown in Figure IV-6.

The internal shroud support was completely shop fabricated, including preliminary machining, at Greenville and shipped as an integral ring assembly to the site where it was welded in place to the bottom head. The final machining was completed after welding.

The stud bolts, washers, and gaskets were shipped directly from General Electric qualified manufacturers to the jobsite storeroom.

4.3 SITE SUBASSEMBLY AND ERECTION

Site subassembly of the reactor vessel started about three months after work began on the containment vessel. Erection of the reactor bottom head followed the completion of the leak rate test of the drywell. The bottom head and stub skirt was welded to the reactor support skirt which was attached to the drywell prior to the leak rate test.

Unlike the case for determining the maximum size of subassemblies at the shop, weight of the lifts or derrick capacity dictated the subassemblies that could be made at the site. The closure seams between subassembled sections were made in place.

The postweld heat treatment zones were established by the location of penetrations with respect to circumferential weld joints and the adherence to safe thermal gradients through adjacent vessel materials.

Methods of achieving the machined surface requirements, drilling and tapping and boring operations were developed by CB&I engineers using commercial equipment, where available, and designing and building custom-made devices, where necessary.

Suitable weather protection devices were provided to shelter the vessel weldments during ground assembly, welding, and postweld heat treatment.

The postweld heat treatment furnaces were also used for environmental housings for the welding and radiographic work. Figure IV-7 shows typical postweld heat treatment of the longitudinal ring welds. Figures IV-8 and IV-9 similarly show postweld heat treatment of the bottom head and stub skirt assembly and the top head and flange assembly.

Temperatures from thermocouples were permanently recorded on a multiple point potentiometer instrument. Adequate thermocouples were used to obtain representative readings from all parts of the section being heated.

The various parameters for heat treating, such as heating and cooling rate, variation of temperature during the holding period, etc., were in accordance with Section III of the ASME Boiler and Pressure Vessel Code and other requirements of the General Electric specifications.

4.3.1 <u>Site Subassembly</u>

The basic assembly yard fabrication process was performed as follows on the head and shell components: (a) shell halves joined into rings, bottom head to skirt extension, top head to flange on level work tables; (b) preheat to 300°F to 400°F and weld sections together; i.e., four shell rings, one bottom head with skirt and one top head with flange; (c) magnetic particle check weld periodically during deposition of metal as preliminary inspection step and replace any unsound material found therein; (d) hot ultrasonic test welds before postweld heat treatment; (e) post weld heat treat at 1150^{o}F; (f) cool and radiograph welds; (g) ultrasonic welds again; (h) manual overlay welds; (i) postweld heat treat; (j) cool and ultrasonic overlay; (k) dye check overlay.

4.3.2 Assembly and Machining

The bottom head and stub support skirt assembly was set in place, leveled, and welded on a 17-foot diameter tubular support skirt furnished in the drywell base of the containment structure.

The vessel centerline was established as a vertical line of sight using a precise jig transit instrument located below the bottom head and sighting on a target in the geometric center of the center control rod drive penetration.

The leveling and plumbing procedure was repeated after placement of each of the four shell rings. The centerline for the bottom head and skirt assembly was located as shown in Figure IV-10. The No. 1 shell ring, assembled and welded in the assembly yard, was placed as an integral ring in position atop the bottom head. The girth seam was fit, preheated and hand welded. The No. 2 ring was then placed, fit and welded. The preheat was maintained on the bottom head to No. 1 ring girth seam until the No. 1 to No. 2 girth seam was ready for postweld heat treatment. At that time, the two rings were postweld heat treated simultaneously in the temporary furnace. Steps (b) through (k) used for site subassembly (Paragraph 4.3.1) were used for assembly in place.

Non-destructive testing methods in the field were the same as those performed in the shop. Radiography was performed utilizing a 75 to 100 Curie Gamma source with appropriate shielding. Usage of the source was in accordance with the applicable Federal and State regulations.

Concurrent with erection of the vessel shell, the vessel top head weldment was fit and welded to the cover flange in the assembly yard area. After completion of all the welding, postweld heat treatment and examination steps, the top head was positioned for drilling the 5-1/4-inch diameter hold-down bolt holes, as shown in Figure IV-11. With the cover in this same position, the grooves for the two 1/2-inch diameter stainless "O" ring gaskets were machined with the portable CB&I equipment as depicted in Figure IV-12.

After the No. 1 and No. 2 girth seams were postweld heat treated, the temporary furnace was converted into an air-conditioned and ventilated work room around the bottom head and No. 1 shell ring. A temporary cover was installed above this work area so that the balance of the vessel could be erected without interfering with the bottom head work. The holes and sleeves for the 121 6-inch diameter control rod drive thimbles and the 40 2-inch diameter holes for the in-core flux sensors were machined utilizing precision-bored guide templates, optically aligned in a temperature controlled housing to guide a verticle boring bar and cutter head, as shown in Figure IV-13. These methods not only assured that the holes were on accurate centers but that they were plumb.

The vessel closure flange was drilled and tapped in the assembly yard after it was welded to the No. 4 shell ring.

The gasket sealing face on the vessel flange was machined in the assembly yard using the same equipment that was used for machining the top head flange.

Drilling of the control rod drive sleeve holes, welding the sleeves and boring them to the final precision dimension was performed in parallel with the work on the vessel as described above.

4.3.3 Cleaning and Hydrostatic Test

Upon completion of the machining work on the control rod drive sleeves, the reactor head was attached to the vessel in preparation for cleaning. The cleaning of the interior surfaces of the vessel was done using high pressure (approximately 8000 PSI) deionized water containing 500-ppm by weight of TSP. Special care was taken to thoroughly water-blast rinse all areas and crevices to insure complete removal of the TSP solution. The rinsing continued until the effluent conductivity was 5 micro-mho/cm.

Upon completion of the initial cleaning, the vessel was filled with heated deionized water and tested per the requirements of the ASME Code. Upon completion of the overload pressure test, the vessel head was removed and service gaskets installed. The vessel head was then replaced and a leakage rate test was performed between the double "O" ring seals at the design pressure.

Upon completion of the hydrostatic test at design pressure, the test caps were removed from the vessel and replaced with temporary covers. The vessel was once again high pressure blasted with deionized water. After drying the interior surfaces of the vessel, the vessel was sealed to prevent entry of dirt or other foreign materials.

4.4 REACTOR VESSEL QUALITY CONTROL

4.4.1 Objective

The quality control for the Monticello nuclear reactor was directed by a Quality Control Manager with the assistance of Quality Control Coordinators. The primary objective of this group was to coordinate CB&I's many quality connected functions into a system which assured that the reactor vessel produced would meet the quality requirements and to document the fact that these quality requirements were met.

4.4.2 Project Quality Control Organization

Authority lines for project management and project quality control were separated by having both managers report directly to the Regional Operations Manager, who, in turn, reported to the Vice President and Manager of Operations. Company standards and policies for quality control -- or more aptly, quality assurance -- were set by the Quality Control Administrator, who also reported to the Vice President and Manager of Operations. The latter was on the same level as the Vice President and Manager of Welding and Inspection. The Q.C. Coordinator for manufacturing was concerned with only nuclear reactors. The Q.C. Coordinator for engineering, purchasing, and construction was concerned with only this vessel from the date of contract until vessel completion.

4.4.3 Compliance with Specifications

By using check-off type records, spot checking operations as the work progressed, and by auditing all inspections, the plant and site Q.C. Coordinators were able to assure that:

1. Approved procedures were used;
2. The approved procedures were being followed;
3. Required inspections were properly performed;
4. Inspections were witnessed by the customer's Q.C. representative; and
5. The material or part met the required level of quality before it was further processed.

Each item or piece of material received at the shop or at the site was covered by a Work Order and Traveler Card which listed, in sequence, all of the operations and inspections which that particular item or piece underwent. Each operation or inspection was given a unique reference number so that it could be referenced to the report of record. Each operation was referenced to the applicable approved procedure with special notations for witness points or points beyond which further progress was halted until clearance was obtained. Provision was made for sign-off by the supervisor after the operation was completed, by the inspector after the inspection was performed, and by the Q.C. Coordinator as well as the customer's Q.C. representative after each item or piece was reviewed and accepted.

4.4.4 Documents and Records

In addition to the usual records required for presssure vessels built to Section III of the ASME Code, a complete thermal history of all parts and a quality control spread sheet of this vessel will be maintained for the specified time period. Written non-destructive test reports were prepared for each radiographic, ultrasonic, magnetic particle and liquid penetrant inspection. Also, welders' performance qualification certificates and test results are available for review.

The same record, report, inspection or process procedure was used for similar operations regardless of whether performed in the shop or at the site. Traveler Cards, Thermal History, and Spread

Sheets were initiated in the shop and were carried through to the completion of the job.

CHICAGO BRIDGE & IRON COMPANY

160 SANSOME STREET, SAN FRANCISCO, CALIFORNIA 94104

April 1, 1969

Area Code: 415 981-7530

In Quintuplicate

General Electric Company
Atomic Power Equipment Department
Nuclear Energy Division
175 Curtner Avenue
San Jose, California 95125

Monticello Project
P.O. 205-55582-I
Reactor Vessel
Contract 9-5624
Seq. No. SFC-259

Attention: Mr. B. K. Lloyd, Buyer
Mail Code 522

Re: Vessel Fabrication and Assembly Report

Gentlemen:

Following our discussions in your office on March 25, 1969, we have once again reviewed Section IV of the Report prepared for the AEC and issued in November 1966 under the title "Monticello Nuclear Generating Plant - Design, Fabrication and Erection of the Reactor Vessel." Accordingly, we have marked the appropriate technical changes to indicate the revisions made during fabrication and erection of the vessel.

Our attached sheets, marked Attachment A, dated April 1, 1969, describe the technical changes made in Section IV. This Attachment could be modified and issued as an Erratum to the original Report.

As for the submittal of different photographs, we assume that you can review the photographs that have been furnished you in accordance with our terms of the contract and choose those pictures that best depict the actual work done at the jobsite.

With this transmittal, we assume the Vessel Fabrication and Assembly Report is complete as far as Chicago Bridge & Iron Company is concerned.

Very truly yours,

CHICAGO BRIDGE & IRON COMPANY

Robert C. Baker
Contracting Engineer

RCB:aer
Enclosure
9-5624

CHICAGO BRIDGE & IRON COMPANY

MONTICELLO REACTOR VESSEL April 1, 1969

ATTACHMENT A

SECTION	PAGE	COMMENT
4.2	IV-3	First Paragraph: Revise to reflect that all shell fittings were shop installed.
4.3	IV-3	First Paragraph: Site subassembly began about three months after work started on the containment. Erection of the reactor bottom head followed the completion of the leak rate test of the containment vessel.
4.3.1	IV-4	First Paragraph: Revise Item (f) to read "cool and ultrasonic welds" and Item (g) to read "radiograph welds."
4.3.2	IV-5	First Paragraph, Ninth Line: Delete reference to the shroud support skirt.
4.3.2	IV-5	Second Paragraph: Revise to indicate that the radiography work was done with a 75 to 100 Curie Gamma source.
4.3.2	IV-5	Last Paragraph: Revise to indicate that the vessel closure flange was drilled and tapped in the assembly yard after being welded to the No. 4 shell ring.
4.3.2	IV-6	First Paragraph: Revise to read that the gasket sealing face on the vessel flange was machined in the assembly yard using the same equipment as was used for machining the top head.
4.3.2	IV-6	Second Paragraph: Delete this paragraph.
4.3.3	IV-6	First Paragraph: Revise the Section to indicate that, after completion of work and placement of the reactor head on the vessel, the interior surfaces of the vessel were cleaned using high-pressure

CHICAGO BRIDGE & IRON COMPANY

SECTION	PAGE	COMMENT
		deionized water containing 500 parts per million by weight of TSP. Special care was taken to thoroughly waterblast rinse all areas and crevices to insure complete removal of the TSP solution. The rinsing continued until the conductivity of the effluent was measured at 5 micro-mho/cm. Following the Code hydrotest, the vessel was once again high-pressure blasted with deionized water.
4.4.1	IV-6	First Paragraph: Add the comment that, in addition to the control rod penetrations, the instrument nozzles in the third and fourth ring were partial penetration weld connections. These partial penetration welds used details per Figure N-462.4(d) in Section III of the 1965 ASME Code.
4.4.2	IV-7	Second Paragraph: Delete the note in the parenthesis. All nozzles were installed in the shop.
4.5.8	IV-20	First Paragraph: In the second line, delete "CB&I Quality Control Coordinators will maintain a Daily Progress Recond."
4.5.8	IV-21	First Paragraph: Delete this paragraph.
4.5.8	IV-21	Fourth Paragraph: Delete the first two sentences.

EXHIBIT 6

INDEPENDENT STRESS ANALYSIS REPORT

INDEPENDENT REVIEW OF STRESS ANALYSIS REPORT

In accordance with a suggestion by the USAEC Advisory Committee on Reactor Safety (Monticello ACRS Letter, April 13, 1967, AEC Docket #50-263), the Reactor Pressure Vessel Stress Analysis Report was reviewed by independent experts. This study has been performed by Teledyne Materials Research Division of the Teledyne Company, Waltham, Massachusetts.

Teledyne's summary letter concerning their review is included herewith as Exhibit 6 of this report.

TELEDYNE MATERIALS RESEARCH
303 BEAR HILL ROAD
WALTHAM, MASSACHUSETTS 02154
617) 899-1350

A TELEDYNE COMPANY

September 15, 1969
Project E-1113

General Electric Company
Nuclear Energy Division
175 Curtner Avenue
San Jose, California 95125

Subject: GE PO #205-F0144 Audit of Monticello Vessel Design Analysis

Attention: Mr. D. K. Heising

Gentlemen:

Teledyne Materials Research has completed the audit of the stress analysis report of the Monticello - NSP Reactor Vessel. On the basis of our review of the final report, we are of the opinion that:

1) The analytical methods employed by General Electric Co. and Chicago Bridge and Iron Co. are consistent with the state-of-the-art as generally practiced in the industry.

2) The ASME code interpretations employed with respect to the analytical results are proper.

Very truly yours,
TELEDYNE MATERIALS RESEARCH

W. E. Cooper

William E. Cooper
Vice President

WEC/mef

86-020

EXHIBIT 7

REACTOR VESSEL DESIGN
SPECIFICATION (REPAIRS)

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION

REVISION STATUS SHEET

22A5541
CONT ON SHEET 2 SH NO. 1

DOCUMENT TITLE REACTOR VESSEL

☒ SPECIFICATION ☐ DRAWING ☐ OTHER

TYPE DESIGN SPECIFICATION (REPAIR)

FMF N/A

MPL No. N/A

LEGEND OR DESCRIPTION OF GROUPS

REVISIONS IDENTIFIED WITH A SPADE (♣)

REVISIONS C

tds	0	DMD-2139 A,B,C.	
t	1	NE GARBER	E.S.
		NE92594 CHKD BY: A LONG SEP 2 2 1977	
t	2	LJ POWELL JAN 17 1978	E.S.
		NE92646 CHKD BY: A LONG	

390	150	1252		
937	518			
519	PR			
1320	229			
200	746			
458	354			
602	312			

PRINTS TO

MADE BY D. SOLOT JULY 29, 1977	APPROVALS J.E.CHARNLEY 8 Aug 1977	DEPT NED	LOCATION SAN JOSE
CHKD BY R.L.SILVA AUG 2-77	ISSUED E. SAXON AUG 03 1977	CONT ON SHEET 2	SH NO. 1

1. SCOPE

1.1 This specification gives the functional and engineering requirements for feedwater nozzle and safe end repair. The repair consists of removing cladding from the nozzle blend radius and bore, machining the safe end to accept a feedwater sparger interference fit thermal sleeve with a piston ring seal, and removal of any remaining linear liquid penetrant indications.

1.2 This specification replaces the original Reactor Pressure Vessel Design Specification for the Reactor Pressure Vessel Feedwater Nozzles and Safe Ends.

2. APPLICABLE DOCUMENTS

2.1 General Electric Documents. The following documents form a part of this specification to the extent specified herein.

2.1.1 Supporting Documents

a.	Thermal Sleeve	112D1696
b.	Feedwater Nozzle Inside Machining Drawing	767E204
c.	Cleaning and Cleanliness Control for Assembly of Reactor Components	21A2045
d.	Reactor Vessel Modification	769E367
e.	Vessel Feedwater Nozzle Blend Radii Crack Removal Tooling	22A4705
f.	Thermal Sleeve End	112D1693

2.1.2 Supplementary Documents. None

2.2 Codes and Standards. The following codes and standards form a part of this specification to the extent specified herein.

a. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code

(1) Section XI, Inservice Inspection of Nuclear Reactor Cooling Systems, 1974 Edition with Addenda to and including the Summer 1975 Addenda.

(2) Section III, Nuclear Power Plant Components, 1974 Edition with Addenda to and including the Summer 1976 Addenda.

(3) Code Case 1804.

3. DESCRIPTION

3.1 The repair will minimize damage to the feedwater nozzle due to thermal cycling. This repair will be performed in accordance with Section XI of the ASME Boiler and Pressure Vessel Code.

4. REQUIREMENTS

4.1 Code. The repair shall be performed in accordance with the requirements of Articles IWA-4000 and IWB-4000 of Section XI of the ASME Code.

4.2 Functional

4.2.1 The machined safe end shall be compatible with interfacing thermal sleeve shown on Drawings 112D1693 and 112D1696.

4.2.2 Clad removal and the safe end machining shall be compatible with the generic feedwater nozzle inside machining specified on Drawing 767E204 and with Drawing 769E367, and shall be performed in accordance with Specification 22A4705.

4.2.3 All work shall be performed in accordance with Specification 21A2045.

4.2.4 Repair of Linear Indications. If any linear indications are detected after machining is completed, they shall be removed in the following manner.

4.2.4.1 Remove all unacceptable indications by grinding.

4.2.4.2 After the unacceptable indications have been removed, the sides of the cavity shall be ground to merge smoothly with adjacent surfaces. In the hoop direction, the sides shall be merged with a minimum blend slope of 4:1 (width to depth). In the axial direction, the sides shall be merged with a minimum blend slope of 2:1 (width to depth). The cavity shall be round bottomed with a minimum radius of two times the depth of the material removed from the final machined surfaces.

4.3 Design

4.3.1 Thermal Sleeve Reactions. The Inconel thermal sleeve shown on Drawing 112D1693 will be installed with a cold nominal interference of 0.010 inch across the diameter. The effects of the thermal sleeve on the safe end and nozzle shall be considered in the design analysis. The geometry is shown in Figure 2 and on Drawing 769E367.

4.3.2 Design pressure is 1250 psig. Normal operating pressure is 1111 psig.

4.3.3 Design temperature is 575°F. Normal operating temperature is 546°F.

4.3.4 Normal operating condition pipe reaction loads are shown in Figure 1. There are no upset, emergency, or fault pipe loads specified for this design.

F_C	3.0 kips
F_L	5.7 kips
F_Z	3.2 kips
M_C	156.0 in.-kips
M_L	336.0 in.-kips
M_Z	348.0 in.-kips

Loads can be in either direction for all values shown.

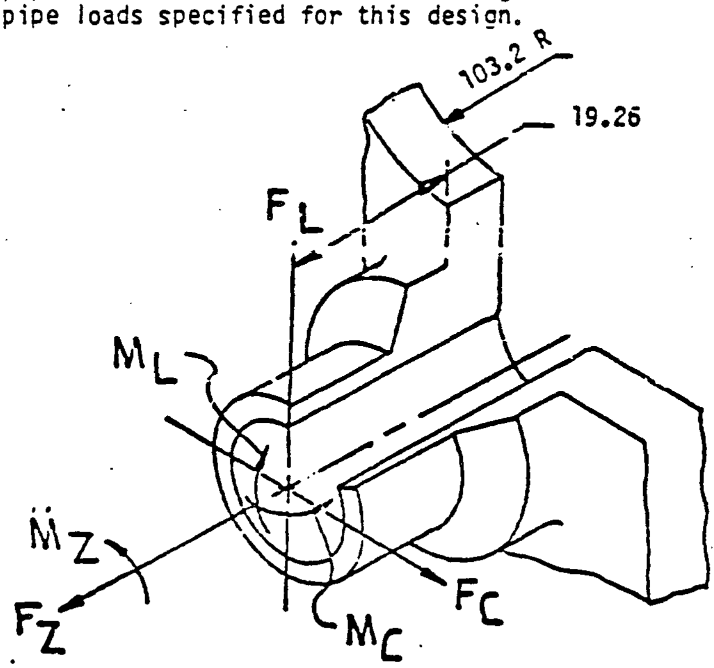


Figure 1

4.3.5 Seismic loads are included in the pipe reactions.

4.3.6 Corrosion Allowance. All exposed exterior ferritic steel surfaces of pressure containing parts shall have a corrosion allowance of 0.032 inch in 40 years. All ferritic steel surfaces exposed to reactor coolant shall have a corrosion allowance of 0.063 inch in 40 years.

4.3.7 Design Life. The design life of this repair shall be not less than 24 months. If design life is extended beyond 24 months, then additional analysis, according to this specification, is required.

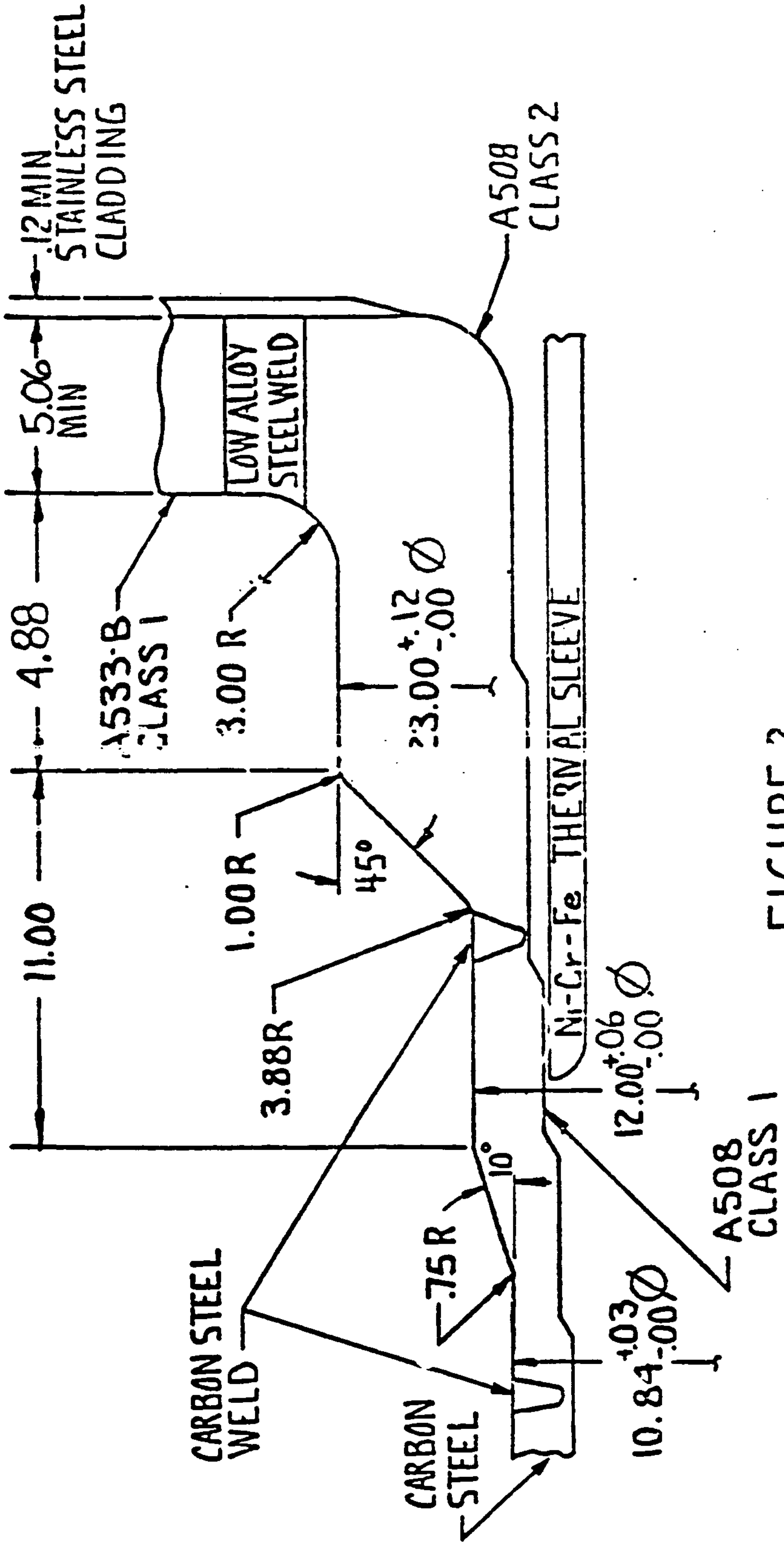

.12 MIN
STAINLESS STEEL
CLADDING
A508
CLASS 2
5.06
MIN
LOW ALLOY
STEEL WELD
4.88
A533-B
CLASS I
3.00 R
23.00 +.12 -.00 Ø
11.00
1.00 R
45°
Ni-Cr-Fe THERMAL SLEEVE
3.88R
12.00 +.06 -.00 Ø
A508
CLASS I
10°
.75 R
CARBON STEEL
WELD
CARBON
STEEL
10.84 +.03 -.00 Ø

FIGURE 2

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4.4 Operational Environment

4.4.1 Neutron fluence is negligible at the feedwater nozzle.

4.4.2 It shall be assumed that the interior of the nozzle and safe end interior of the nozzle and safe end are exposed to saturated steam and demineralized water under operating conditions.

4.4.3 Insulation. Exterior surfaces of the nozzle and safe end are insulated. The average heat transfer rate under operating conditions is 80 Btu/hr-ft^2.

4.4.4 Heat Transfer Coefficients. The heat transfer coefficients defined below are from emperical data for this design and are to be used in the analyses required in Section 5. Heat transfer coefficients for other locations shall be calculated by conventional methods.

4.4.4.1 The heat transfer coefficient for the nozzle inside surface (areas A thru D in Figure 3) for all leakage flow rates is:

$$h = \frac{Z \text{ @ Annulus fluid temperature}}{Z \text{ @ } 500°F} \times \left(\frac{Q}{Q_R}\right)^{.8} \times 9000 \frac{\text{Btu}}{\text{hr-ft}^2\text{-°F}}$$

The minimum value of h shall be 1[illegible]00 Btu/hr-ft^2-°F.

4.4.4.2 The heat transfer coefficient for the inside of the safe end and thermal sleeve that is exposed to the feedwater flow is:

$$h = \frac{Z \text{ @ Feedwater temperature}}{Z \text{ @ } 100°F} \times \left(\frac{Q}{960}\right)^{.8} \times 2600 \frac{\text{Btu}}{\text{hr-ft}^2\text{-°F}}$$

4.4.4.3 Nomenclature

$$Z = \frac{K\, P_r^{1/3}}{\nu^{.8}}$$

K = Thermal conductivity of the fluid

P_r = Prandtl Number

ν = Kinematic viscosity

Q = Feedwater flow per nozzle (gpm)

Q_R = Feedwater flow per nozzle at 100% rated power (gpm) as defined in Paragraph 4.5.1.3.

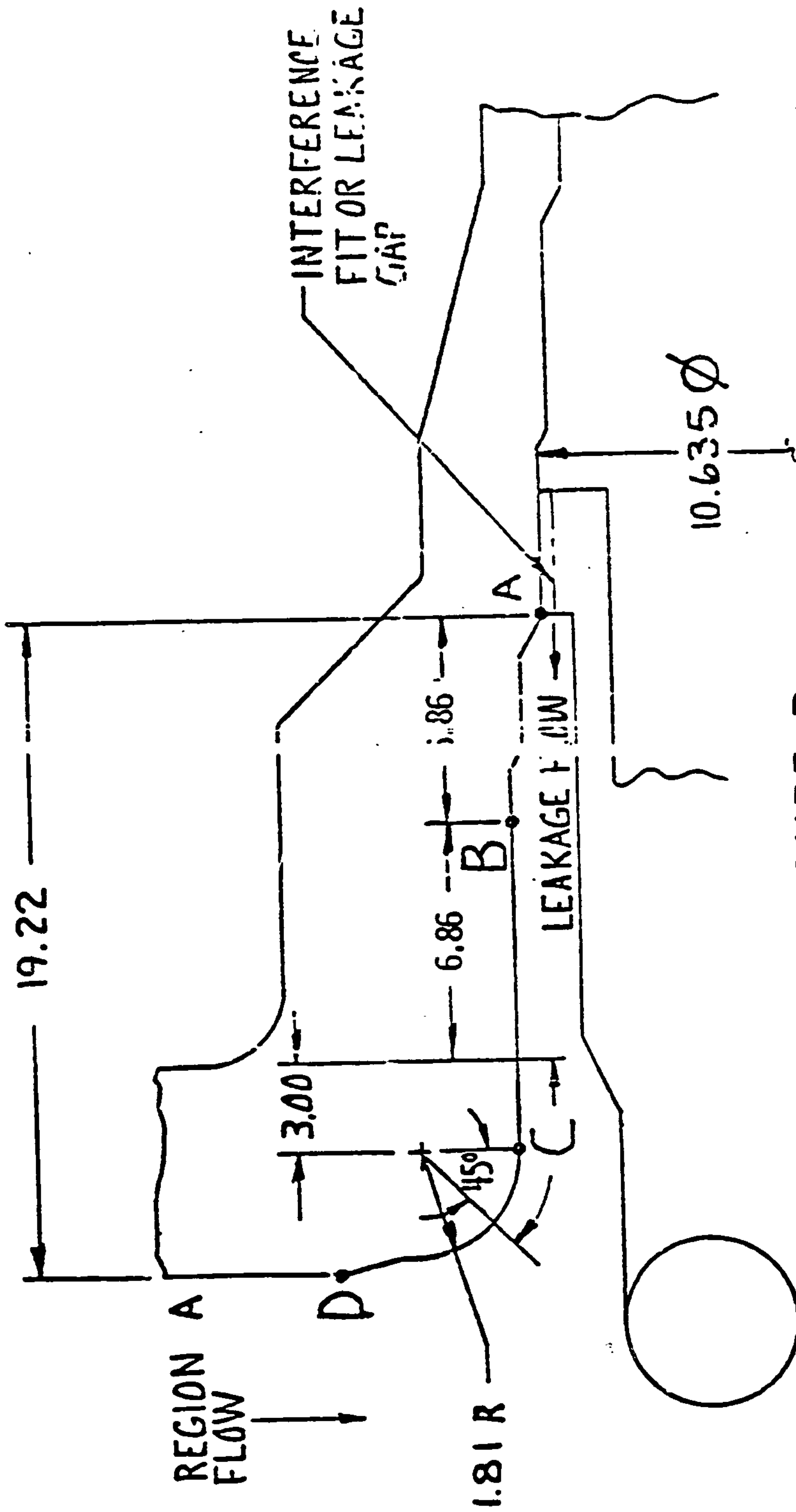
INTERFERENCE FIT OR LEAKAGE GAP
FW FLOW
10.635 Ø
A
19.22
6.86
6.86
B
LEAKAGE FLOW
3.00
45°
C
D
REGION A FLOW
1.81 R

FIGURE 3

4.4.4.4 The heat transfer coefficient for the inside of the vessel shell outside of areas A through D shall be 1000 Btu/hr-ft^2-°F for all conditions.

4.4.5 Annulus Fluid Temperature

$$T = T_{FW} + (C_1) \times (C_2) \times (T_A - T_{FW})$$

where

T = annulus fluid temperature

T_{FW} = feedwater fluid temperature

T_A = Region A fluid temperature = 546°F

C_1 = Coefficient from Table 1

C_2 = Coefficient from Figure 4

Table 1 Coefficient C_1

Flow \ Location (see Figure 3	A	B	C	D
100% rated feedwater flow	0.44	0.59	0.72	0.88
20% rated feedwater flow	0.66	0.88	0.96	0.96
0% rated feedwater flow	1.0	1.0	1.0	1.0

Interpolate linearly between defined points A, B, C, and D and between flow rates given.

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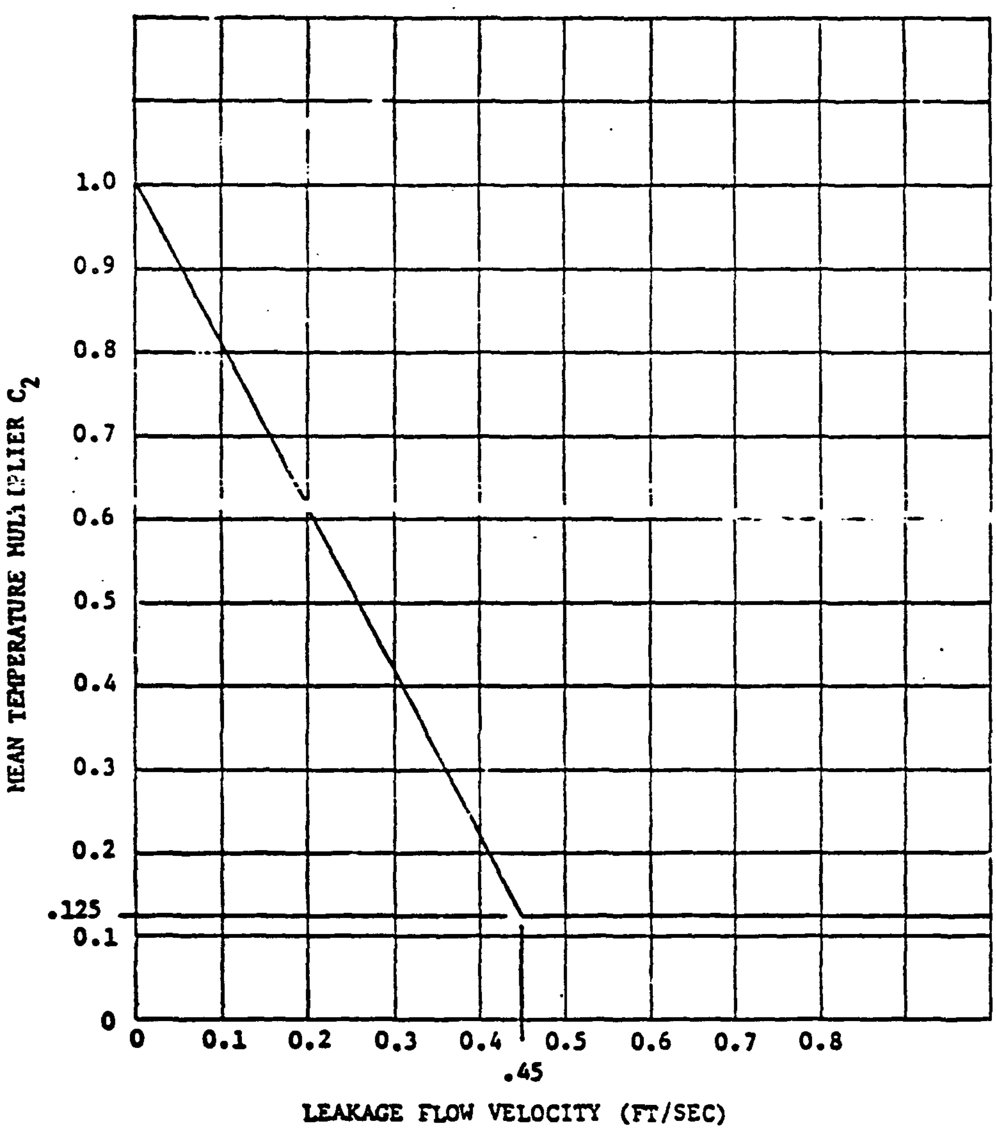

FIGURE 4

4.5 Cyclic Conditions. There are three sources of normal operation thermal cycles, system cycling, unstable flow cycling, and rapid mixing cycling. There are no upset, emergency, or fault thermal cycles specified for this design.

4.5.1 System Cycling. This type cycling results from changes in the flow and temperature of the feedwater and/or of the reactor water.

4.5.1.1 Seventy-five cycles of the following transient represent the equivalent of 24 months of this type of cycling.

4.5.1.2 The temperature transient consists of:

4.5.1.2.1 Initial Condition. The nozzle, safe end, thermal sleeve and all contained water is isothermal at 100°F and is at 0.0 psig.

4.5.1.2.2 The nozzle, safe end, and thermal sleeve are heated by the contained water. The water is heated from 100°F to 546°F at a rate of 100°F/hr. The pressure is increased to 1111 psig.

4.5.1.2.3 The hot feedwater is displaced by 100°F feedwater with a velocity of 5 ft/sec. This condition exists until steady state is achieved.

4.5.1.2.4 The feedwater temperature then steps to 200°F.

4.5.1.2.5 The feedwater temperature then is increased to 376°F at 250°F/hr. Simultaneously the feedwater flow velocity is increased from 5 ft/sec to 20 ft/sec. The end points, 376°F and 20 ft/sec are reached simultaneously. This condition exists until steady state is achieved.

4.5.1.3 Feedwater flow rate shall be obtained from feedwater velocity by using an area of 64.5 square inches. The velocity that corresponds to 100% rated feedwater flow is 20 ft/sec at a temperature of 376°F.

4.5.1.4 The temperature transient is shown in tabular form below:

TEMPERATURE TRANSIENT

Fluid Temp. Rate	Fluid Start Temp.	Fluid End Temp.	State of Fluid	Fluid Velocity	Vessel Pressure	Notes
100 F/hr	100	546	Water	0	1111 psig	Followed by Step To
0	100	100	Water	5 ft/sec	1111 psig	Followed by Step To
250 F/hr	260	376	Water	5* ft/sec	1111 psig	

*Velocity changes linearly 5 ft/sec to 20 ft/sec

4.5.2 Unstable Flow Cycling. During reactor startup under low power conditions temperatures in the top half of the feedwater nozzle safe end and thermal sleeve shall be assumed to fluctuate over a 250°F temperature range from (100°F to 350°F) as shown on Figure 5, for 1% of the operating time, i.e., 88 hours per year. This cycling is in addition to the temperature cycling in the nozzle defined in Paragraph 4.5.1. This cycling is due to unstable flow when the feedwater flow rate is too low to keep the hot region A fluid swept out of the sparger, thermal sleeve, and safe end. The bottom half of the thermal sleeve and nozzle remain at 100°F during this cycling. The heat transfer coefficient, calculated according to the procedure given in Paragraph 4.4.4.2 at 25% rated feedwater flow, is to be used for the top and bottom for both cold flushing and hot back flow. The transient stresses may be calculated by assuming an axisymmetric model with boundary conditions for the top half of the nozzle. The stresses due to the top-to-bottom temperature may be upper bounded by assuming that the vessel shell, nozzle forging, and attached piping are rigid and using an equation of the form

$$\sigma_X = \mp \frac{E\,\alpha\,(T_{Top} - T_{Bottom})}{2} \text{ for the safe end.}$$

where

σ_X = axial membrane stress in safe end, use upper sign for top, lower sign for bottom

E = Youngs Modulus

α = coefficient of thermal expansion

T_{Top} = mean temperature of top half of safe end

T_{Bottom} = mean temperature of bottom half of safe end

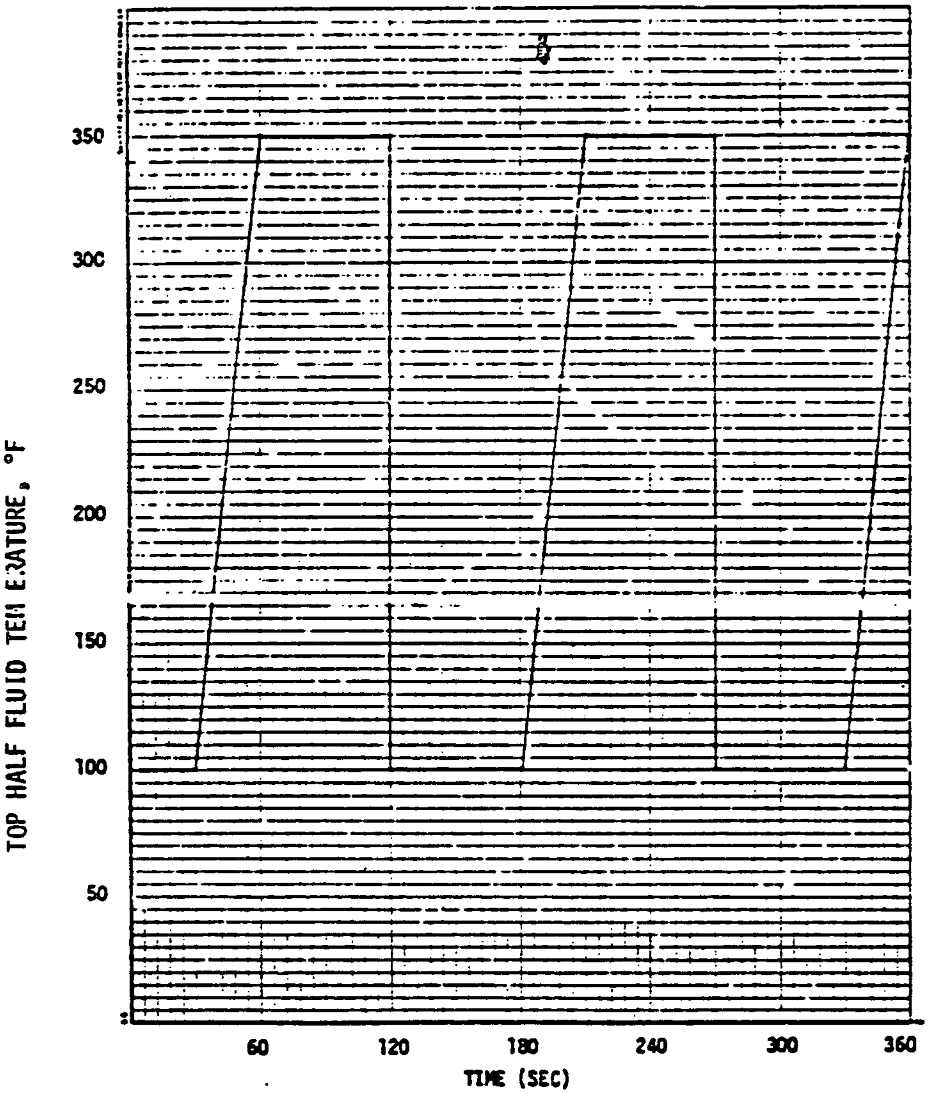
TOP HALF FLUID TEMPERATURE, °F
350
300
250
200
150
100
50
60
120
180
240
300
360
TIME (SEC)

FIGURE 5

4.5.3 Rapid Cycling

4.5.3.1 Rapid temperature cycling (on the order of 0.1 Hz to 1.0 Hz) occurs as a result of cold feedwater being injected into a hot reactor. The most dominant cause of this cycling in the nozzle bore and on the blend radius is turbulent mixing of leakage flow with region A fluid. Rapid cycling is caused in the absence of leakage flow by turbulent region A fluid causing the thermal boundary layer around the cold thermal sleeve to be broken up and swept against the nozzle. Incompletely mixed sparger discharge flow and region A fluid that is carried back to the nozzle also causes some rapid cycling.

4.5.3.2 The metal surface temperature ranges are given by the following empirical equation:

$$\Delta T_{p-p} = \bar{A} \times C_3 \times C_4 \times (T_A - T_{FW})$$

where:

ΔT_{p-p} = metal surface peak to peak temperature range

$\bar{A}$ = amplitude coefficient for a given frequency of cycling, from Table 2

C_3 = coefficient from Table 3

C_4 = coefficient from Figure 6

T_{FW} and T_A are defined in Table 4.

4.5.3.3 The amplitudes and cycles given in Table 2 and the flow/temperature/time data from Table 4 are to be used in the fatigue evaluation. (The design life is given in Paragraph 4.3.7.)

Table 2 Amplitude/Frequency Data for Rapid Cycling

Index I	Amplitude $\bar{A}$	Frequency Cycles/hr
1	1.00	15
2	0.95	30
3	0.90	30
4	0.85	75
5	0.77	120
6	0.66	150
7	0.56	180
8	0.46	225
9	0.36	375
10	0.26	375
11	0.15	1125

Table 3 Coefficient C_3

Pt.	100% Rated Feedwater Flow	20% Rated Feedwater Flow	0% Rated Feedwater Flow
A	0.20	0.12	0.12
B	0.20	0.12	0.12
C	0.30	0.18	0.18
D	0.10	0.06	0.06

Interpolate linearly between defined points A, B, C, and D and between given flow rates.

Table 4 Flow, Temperature, and Time Data for Rapid Cycling

Index J	Feedwater Flow % Rated	T_{FW} Feedwater Temperature °F	T_A Region A Temperature °F	Time %	Hours Per Year
1	100	367	546	61.33	5373
2	84	358	546	14.00	1226
3	57	330	546	7.47	654
4	37	300	546	3.73	327
5	10	195	546	3.73	327
6	20	101	546	0.47	41
7	10	101	546	0.93	81
8	2	131	546	0.47	41
9	2	70	546	0.09	7.9
10	84	278	546	0.19	16
11	100	315	546	0.93	81
12	100	278	546	0.00	0.0
13	0	200	200	0.067	5.88
14	0	300	300	0.15	13.38
15	0	400	400	0.24	20.88
16	0	300	340	0.999	87.5
17	1	350	360	0.003	0.25
18	2	190	350	0.020	1.78
19	2	125	340	0.016	1.38
20	2	70	330	0.003	0.25
21	2	190	400	0.018	1.60
22	3	200	340	0.004	0.38
23	0	70	70	5.14	450

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22A5541	SH. NO. 15
REV. 2	

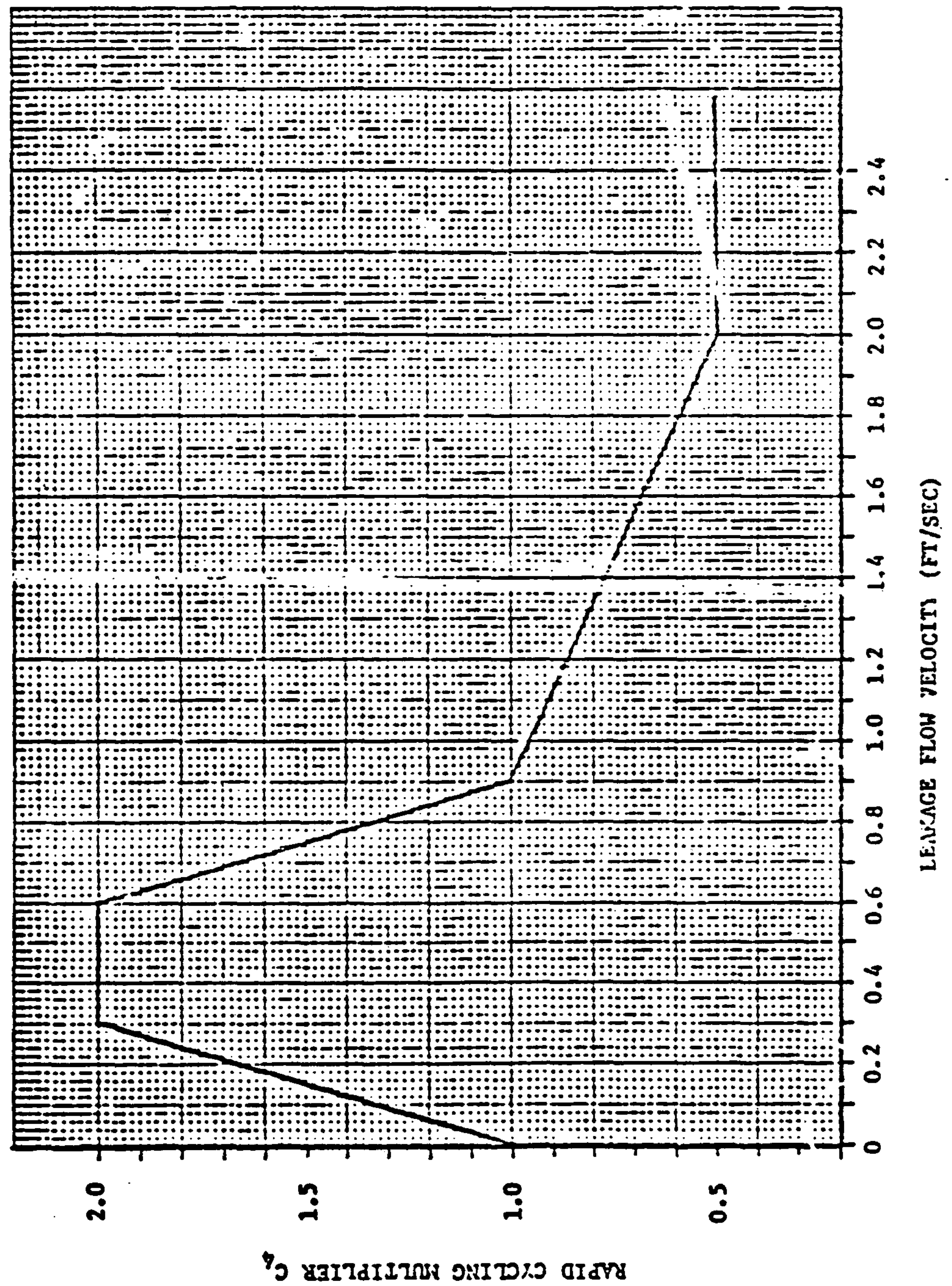

FIGURE 6

4.5.3.4 The alternating stress produced by the rapid cycling shall be calculated using:

$$\sigma_{alt} = \frac{E \alpha \Delta T_{p-p}}{2(1 - \nu)}$$

where:

E (Youngs Modulus) and α (instantaneous coefficient of thermal expansion) are evaluated at a temperature of

$$T = T_A - 0.5 \times C_3 \times C_4 \times (T_A - T_{FW})$$

ν = Poisson's Ratio

ΔT_{p-p}, T_A, C_3, C_4, and T_{FW} are defined in Paragraph 4.5.3.2

4.5.3.5 The fatigue usage factor due to rapid thermal cycling is given by:

$$U = \sum_{\substack{i=1 \\ j=1}}^{23 \;\; 11} U_{ij} \times \text{Design Life}$$

where

U = usage factor due to rapid cycling

U_{ij} = usage factor due to i^{th} amplitude and frequency for the j^{th} flow, temperature, and time

4.5.4 Leakage flow rates are to be calculated for all conditions. The following assumptions are to be used:

a. Neglect the pressure of any seal rings, springs, and ring grooves, i.e., assume the thermal sleeve looks like Figure 3.

b. There is zero leakage flow when there is zero clearance between the thermal sleeve and nozzle.

c. The pressure drop across the thermal sleeve is 10.9 psi at 100% rated feedwater flow.

4.5.4 (Continued)

d. Yielding of the thermal sleeve and safe end (and thus relaxing the initial interference fit) at this leakage gap shall be considered.

e. Changes in the leakage gap due to differential expansions between the nozzle and thermal sleeve must be considered. See Figures 2 and 3 for dimensions and materials for determining leakage gap.

f. The leakage gap (i.e., radial gap) increases at the rate of 0.0017 inch per year due to corrosion.

g. The leakage flow velocity averaged over the annulus area at the discrete point of interest shall be used in determining C_2 and C_4 from Figures 4 and 6 except for zones C and D. Use the maximum average leakage velocity in zone C to determine C_2 and C_4 and use these values for all of zone C. Assume that the leakage velocity varies from the zone C value to zero at point D.

5. ANALYSIS

5.1 Primary Stresses. The final machined and ground nozzle and safe end thicknesses shall satisfy the primary stress requirements of ASME Code Section III, Article NB-3000.

5.2 Secondary and Peak Stresses. The nozzle and safe end shall separately be shown to satisfy the secondary and peak stress requirements of ASME Code Section III, Article NB-3000. The fatigue curve shown on Figure 7 shall be used. The operating pressure and temperature identified in Paragraphs 4.3.2 and 4.3.3 shall be used.

6. DOCUMENTATION

6.1 The required analysis shall be documented in a manner suitable for submission to enforcement and regulatory agencies.

6.2 The required analysis shall be certified.

GENERAL ELECTRIC
NUCLEAR ENERGY DIVISION

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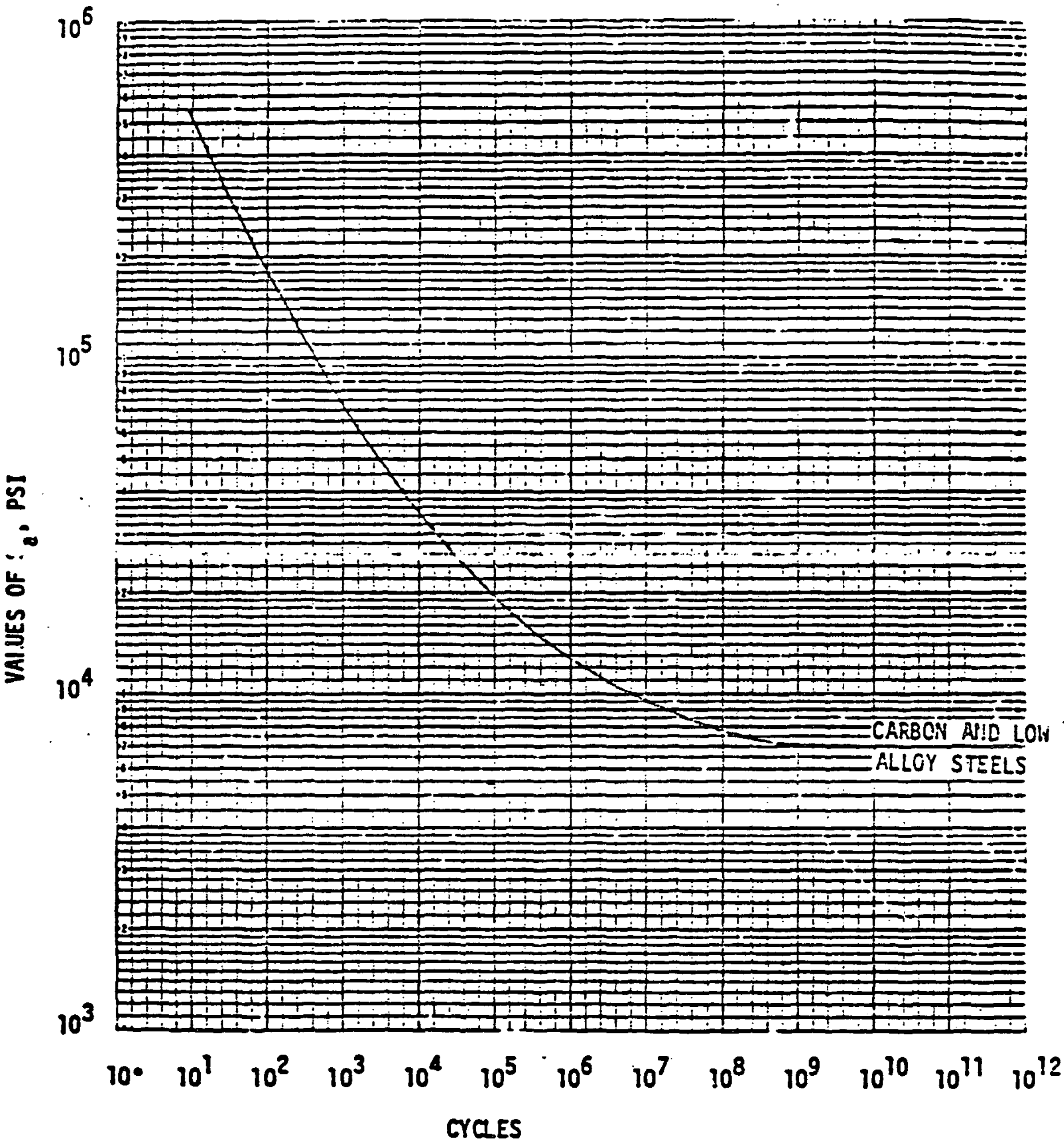
REV. 2	Final



E = 30x10^6psi

FIGURE 7

86-020

EXHIBIT 8

REACTOR VESSEL SYSTEM CYCLING
(STRESS REPORT)

EIS IDENT: RV (SYSTEM CYCLING) 8-2

REVISION STATUS SHEET

22A7454	
CONT ON SHEET 2	SH NO. 1

GENERAL ELECTRIC

NUCLEAR ENERGY BUSINESS GROUP

DOCUMENT TITLE REACTOR VESSEL (SYSTEM CYCLING)

TYPE STRESS REPORT

LEGEND OR DESCRIPTION OF GROUPS

FMF MONTICELLO

MPL ITEM NO. (s) PRODUCT SUMMARY (SECTION 7)

| - DENOTES CHANGE

IMPORTANT TO SAFETY - THIS ITEM IS OR CONTAINS A SAFETY RELATED ITEM YES ☐ NO ☒ EQUIP. CLASS CODE

REVISIONS C

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NUCLEAR ENERGY
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22A7454	SH NO. 2
REV 1	

CERTIFICATION OF STRESS REPORT

This certification for the Monticello Reactor Vessel (System Cycling) feedwater nozzle and safe end repair Stress Report and accompanying documents comprises the Stress Analysis required by Paragraph NCA-3550 of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1977 Edition with Addenda through Summer 1978. I certify that to the best of my knowledge and belief the Stress Analysis Report is correct and complete and in accordance with Design Specification 22A6996, Revision 0, and in compliance with the requirements of Article NB-3000 of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1977 Edition with Addenda through Summer 1978. I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Registered Professional Engineer under the laws of the State of Minnesota.

Type of Document	Title	Document Number	Revision Number
Stress Report	Reactor Vessel Rapid Cycling	22A7227	0
Design Spec	Reactor Vessel System Cycling	22A6996	0

Certified By: James E Charnley P.E. Number: 14372
JAMES E. CHARNLEY

State: Minnesota Date: 9 April 1982

NEBG-807A (6/80)

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1. ABSTRACT

This report documents the stress analysis performed for the feedwater nozzle and safe end assembly. The analysis is concerned with Service Level A, B, and C events, and design conditions. A fatigue analysis was also performed.

This analysis of the feedwater nozzle and safe end assembly is required because of the complete redesign of the existing safe end and thermal sleeve assembly. As a consequence of this redesign, the component's geometries will change from the ones originally analyzed, thus necessitating this report. The nozzle and safe end assembly in this report are analyzed in accordance with the requirements of the ASME Code (Reference 6.2), and the General Electric design specification (Reference 6.1).

2. SUMMARY AND CONCLUSIONS

2.1 It is shown by analysis in this report that the feedwater nozzle and safe end assembly fully meet the stress intensity limits for all design, Service Level A, B, and C conditions. Some of the significant results of this analysis are as follows:

NOTE: These results include the results of Appendix 30.

Maximum design primary stress intensity: (Table 3-2 and Table 30.3.1-1)

P_m = 14.05 ksi ; P_m Allowable = 18.1 ksi

P_{M+B} = 24.38 ksi ; P_{M+B} Allowable = 27.9 ksi

Maximum Level 'C' primary stress intensity: (Table 3-2 and Table 30.3.1-1)

P_m = 15.46 ksi ; P_m Allowable = 27.1 ksi

P_{M+B} = 33.89 ksi ; P_{M+B} Allowable = 41.7 ksi

Maximum range of primary plus secondary stress intensity, P + Q: (Paragraph 4.2.5.4 and Paragraph 30.3.3.4.4)

P + Q = 62.9 ksi

Maximum range of primary plus secondary stress intensity excluding thermal bending: (Paragraph 4.2.5.4 and Paragraph 30.3.3.4.4)

P + Q = 45.94 ksi ; P + Q Allowable = 55.8 ksi

Maximum total fatigue usage due to low and high cycle fatigue plus existing accumulated fatigue: (Paragraph 4.3.6 and Paragraph 30.3.4.2)

U_{max} = 0.439

3. DESIGN REQUIREMENTS

The safe end and thermal sleeve geometry is provided in References 6.8, 6.10, and 6.13. The nozzle geometry is provided in References 6.1 and 6.7. The operating thermal and mechanical loads are provided by Reference 6.1.

This section illustrates accceptance for the design and Service Level C conditions. Primary membrane and primary membrane and bending (sizing) calculations are performed.

In Sections G through J, moments due to thermal sleeve axial loads are assumed negligible.

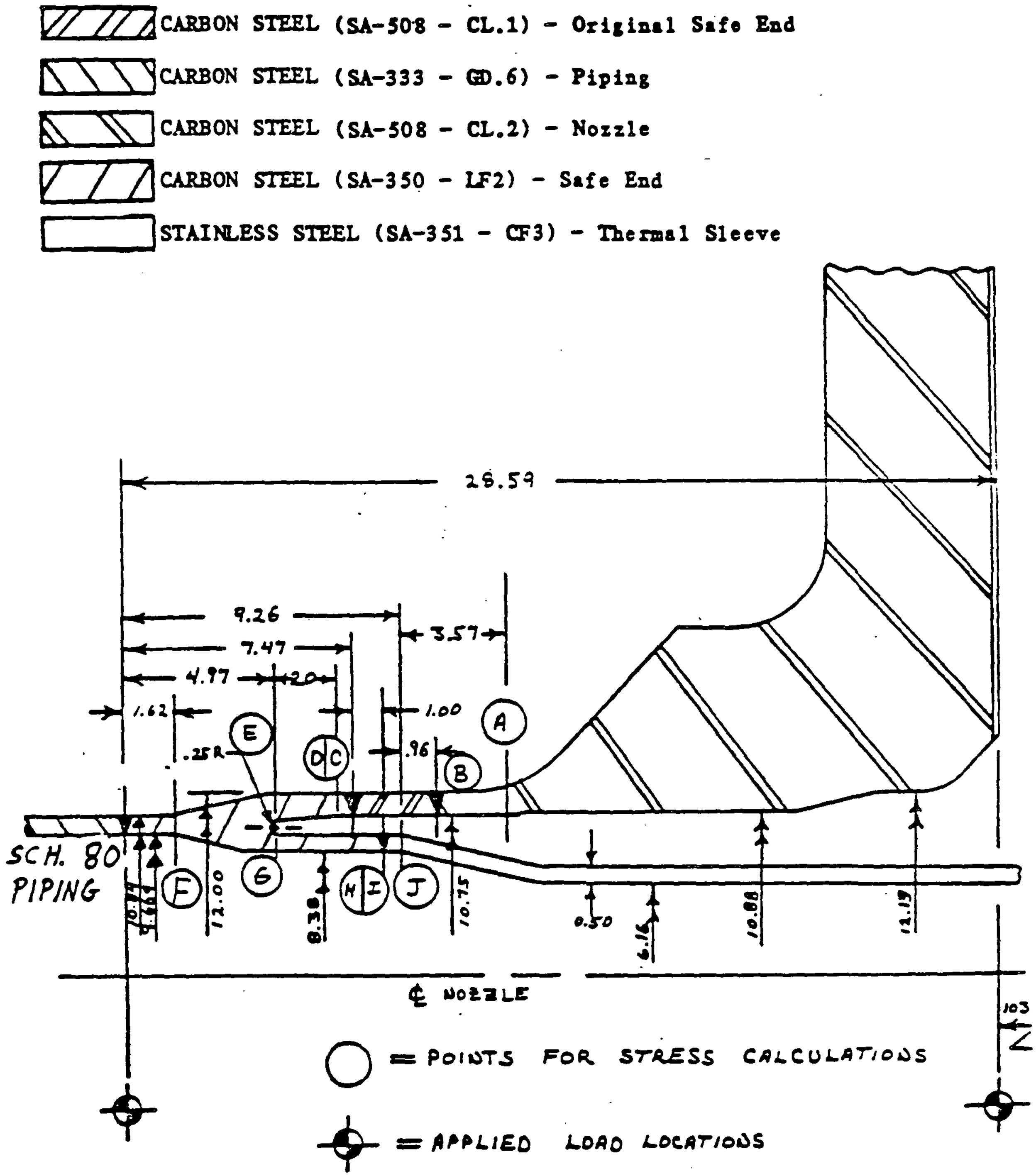


FIGURE 3.1 NOZZLE, SAFE END, AND THERMAL SLEEVE GEOMETRY

TABLE 3-1 SECTION PROPERTIES FOR NOZZLE (Corrosion Included)

Section	Thickness (In.)	Area (In^2)	Section Modulus (In^3)	Material
A	0.531	19.03	51.98	SA-508 (CL.2)
B	0.531	19.03	51.98	SA-508 (CL.1)
C	0.531	19.03	51.98	SA-508 (CL.1)
D	0.531	19.03	51.98	SA-350 (LF2)
E *	0.531	19.03	51.98	SA-350 (LF2)
F	0.4917	15.89	39.09	SA-350 (LF2)
G	0.375	10.46	22.32	SA-350 (LF2)
H	0.375	10.46	22.32	SA-350 (LF2)
I	0.494	13.78	29.07	SA-351 (CF3)
J	0.494	13.78	29.07	SA-351 (CF3)

* Section A properties used here (conservative)

$$\text{Area} = \pi/4\ (D_o^2 - D_i^2)$$

D_o = (Outside Diameter - Corrosion)

$$\text{Section Modulus} = \frac{I}{C} = \frac{\pi/64\ (D_o^4 - D_i^4)}{D_o/2}$$

D_i = (Inside Diameter - Corrosion)

Corrosion Allowances (Reference 6.1)

Exterior Exposed Carbon Steel	1/32 inch
Interior Exposed Carbon Steel	1/16 inch
Interior Exposed Stainless Steel	0.003 inch

Material Allowables (Reference 6.2)

			S_m (at 550°F)
Carbon Steels	SA-508	CL.1	18.1 ksi
	SA-508	CL.2	26.7 ksi
	SA-350	LF2	18.6 ksi
	SA-333	GD.6	18.1 ksi
Stainless Steels	SA-351	CF3	16.0 ksi

Loading

Nozzle Safe End Loads (Reference 6.1)

Forces in kips
Moments in in-kips

	Condition	F_x	F_y	F_z	M_x	M_y	M_z	$R_{(in)}$
Design	-	2.54	3.15	2.28	387.6	172.9	324.6	131.6
Nozzle	Dead Wt.	- 0.11	- 0.63	0.15	11.6	- 14.1	- 11.1	
'A'	Seismic	± 0.29	± 2.51	± 2.23	± 9.3	± 158.9	± 313.4	131.6
Loads	Thermal	0.02	0.16	- 0.21	- 12.0	- 12.1	- 45.0	
Nozzle	Dead Wt.	- 0.07	0.18	- 0.04	- 7.0	- 2.1	- 7.3	
'B'	Seismic	± 2.44	± 1.97	± 0.26	± 376.0	± 106.3	± 10.6	131.6
Loads	Thermal	0.82	- 4.34	1.37	267.2	- 66.7	- 1.4	

Thermal Sleeve Loads (Reference 6.1)

Forces in kips
Moments in in-kips

Condition	F_x	F_y	F_z	M_x	M_y	M_z	$R_{(in)}$
Design	2.5	0.6	5.7	2.4	2.0	0	103.0
Dead Wt.	0	- 0.3	- 0.5	- 1.2	0	0	
Seismic	± 2.5	± 0.3	± 1.5	± 1.2	± 2.0	0	103.0
Thermal	0	0	- 1.2	0	0	0	
Hydraulic	0	0	- 2.5	0	0	0	

Emergency condition (Service Level 'C') defined in Reference 6.1 as follows:

Normal operation plus two times Seismic Loads

To calculate the largest nozzle loads, use the following:

$$P = (F_x^{\,2} + F_y^{\,2})^{1/2}$$

$$M = (M_x^{\,2} + M_y^{\,2} + M_z^{\,2})^{1/2}$$

Nozzle 'A' Loading (Service Level 'C')

P = 5.70 kip

M = 721.5 in-kip

F_z = 4.61 kip

Nozzle 'B' Loading (Service Level 'C')

P = 6.44 kip

M = 789.3 in-kip

F_z = 0.56 kip

Therefore, the following loads are used for the design and Service Level 'C' conditions: (Note: No faulted condition exists)

Nozzle Loads

Forces in kips
Moments in in-kips

Condition	P	M	F_z
Design	4.05	534.4	2.28
Service Level 'C'	6.44	789.3	4.61

Thermal Sleeve Loads

Forces in kips
Moments in in-kips

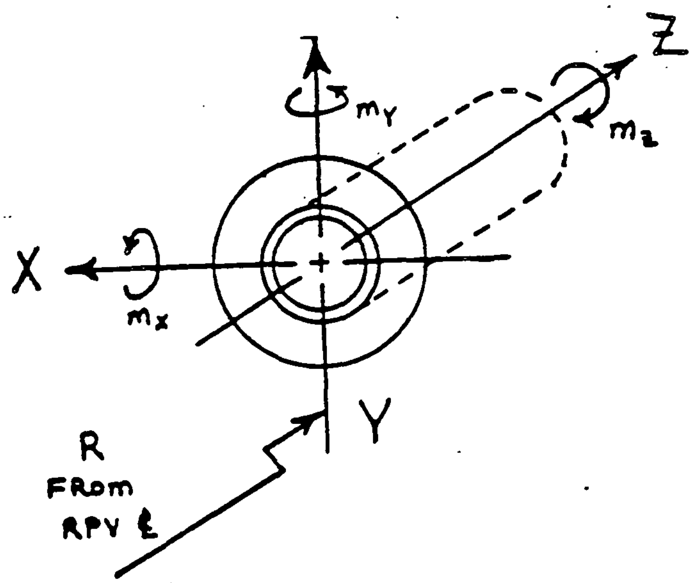
Condition	P	M	F_z
Design	2.57	3.124	5.7
Service Level 'C'	5.08	5.39	6.0

Pressure Loads (Reference 6.1)

Design Pressure = 1,250 psi

Service Level 'C' Pressure = 1,375 psi

Loading Sign Convention



Sign Convention applies to both safe end and thermal sleeve loadings.

Section A

Design Pressure Stress:

$$\sigma_\theta = \frac{P\ D_i}{2t} = \frac{1,250\ (10,875)}{2\ (0.531)} = 12,800 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 6,400 \text{ psi}$$

$$\sigma_r = -1,250 \text{ psi}$$

Stress Due To Nozzle Loads:

$$P = 4.05 \text{ kip}$$

$$M = 534.4 \text{ in-kip}$$

$$F_z = 2.28 \text{ kip}$$

$$m = 534.4 + 4.05\ (12.83) + 2.28\ (0.56) = 587.64 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{587.64}{51.98} = 11.31 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{2.28}{19.03} = 0.12 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 2.57 \text{ kip}$$

$$M = 3.124 \text{ in-kip}$$

$$F_z = 5.7 \text{ kip}$$

$$m = 3.124 + 2.57\ (15.76) + 5.7\ (2.36) = 57.08 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{57.08}{51.98} = 1.1 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{5.7}{19.03} = 0.30 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 6{,}400 + 11{,}310 + 120 + 1{,}100 + 300 = 19{,}230 \text{ psi}$$

$$\sigma_\theta = 12{,}800 \text{ psi}$$

$$\sigma_r = -1{,}250 \text{ psi}$$

Section A

Service Level 'C' Pressure Stress:

$$\sigma_\theta = \frac{P\,D_i}{2t} = \frac{1{,}375\ (10.875)}{2\ (0.531)} = 14{,}081 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 7{,}040 \text{ psi}$$

$$\sigma_r = -1{,}375 \text{ psi}$$

Stress Due To Nozzle Loads:

$$P = 6.44 \text{ kip}$$

$$M = 789.3 \text{ in-kip}$$

$$F_z = 4.61 \text{ kip}$$

$$m = 789.3 + 6.44\ (12.83) + 4.61\ (0.56) = 874.51 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{874.51}{51.98} = 16.83 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{4.61}{19.03} = 0.243 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 5.08 \text{ kip}$$

$$M = 5.39 \text{ in-kip}$$

$$F_z = 6.0 \text{ kip}$$

$$M = 5.39 + 5.08\,(15.76) + 6.0\,(2.36) = 99.61 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{99.61}{51.98} = 1.92 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{6.0}{19.03} = 0.316 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 7{,}040 + 16{,}830 + 243 + 1{,}920 + 316 = 26{,}349 \text{ psi}$$

$$\sigma_\theta = 14{,}081 \text{ psi}$$

$$\sigma_r = -1{,}375 \text{ psi}$$

Section B

Design Pressure Stress:

$$\sigma_\theta = \frac{P\,D_i}{2t} = \frac{1,250\ (10.875)}{2\ (0.531)} = 12,800 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 6,400 \text{ psi}$$

$$\sigma_r = -1,250 \text{ psi}$$

Stress Due To Nozzle Loads:

$$P = 4.05 \text{ kip}$$

$$M = 534.4 \text{ in-kip}$$

$$F_z = 2.28 \text{ kip}$$

$$M = 534.4 + 4.05\ (10.22) + 2.28\ (0.56) = 577.07 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{577.07}{51.98} = 11.102 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{2.28}{19.03} = 0.12 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 2.57 \text{ kips}$$

$$M = 3.124 \text{ in-kips}$$

$$F_z = 5.7 \text{ kip}$$

$$M = 3.124 + 2.57\ (18.37) + 5.7\ (2.36) = 63.79 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{63.79}{51.98} = 1.23 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{5.7}{19.03} = 0.30 \text{ ksi}$$

Total Stress

$$\sigma_{\phi} = 6{,}400 + 11{,}102 + 120 + 1{,}230 + 300 = 19{,}152 \text{ psi}$$

$$\sigma_{\theta} = 12{,}800 \text{ psi}$$

$$\sigma_r = -1{,}250 \text{ psi}$$

Section B

Service Level 'C' Pressure Stress:

$$\sigma_\theta = \frac{P\,D_i}{2t} = \frac{1,375\ (10.875)}{2\ (0.531)} = 14,080.2 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 7,040 \text{ psi}$$

$$\sigma_r = -1,375 \text{ psi}$$

Stress Due To Nozzle Loads:

$$P = 6.44 \text{ kip}$$

$$M = 789.3 \text{ in-kip}$$

$$F_z = 4.61 \text{ kip}$$

$$M = 789.3 + 6.44\ (10.22) + 4.61\ (0.56) = 857.7 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{857.7}{51.98} = 16.501 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{4.61}{19.03} = 0.243 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 5.08 \text{ kips}$$

$$M = 5.39 \text{ in-kips}$$

$$F_z = 6.0 \text{ kip}$$

$$M = 5.39 + 5.08\ (18.37) + 6.0\ (2.36) = 112.87 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{112.87}{51.98} = 2.172 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{6.0}{19.03} = 0.316 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 7{,}040 + 16{,}501 + 243 + 2{,}172 + 316 = 26{,}272 \text{ psi}$$

$$\sigma_\theta = 14{,}080 \text{ psi}$$

$$\sigma_r = -1{,}375 \text{ psi}$$

Section C/D

Design Pressure Stress:

$$\sigma_\theta = \frac{P\ D_i}{2t} = \frac{1{,}250\ (10.875)}{2\ (0.531)} = 12{,}800 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 6{,}400 \text{ psi}$$

$$\sigma_r = -1{,}250 \text{ psi}$$

Stress Due To Nozzle Loads:

$$P = 4.05 \text{ kip}$$

$$M = 534.4 \text{ in-kip}$$

$$F_z = 2.28 \text{ kip}$$

$$M = 534.4 + 4.05\ (7.47) + 2.28\ (0.56) = 566.0 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{566.0}{51.98} = 10.89 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{2.28}{19.03} = 0.12 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 2.57 \text{ kips}$$

$$M = 3.124 \text{ in-kips}$$

$$F_z = 5.7 \text{ kip}$$

$$M = 3.124 + 2.57\ (21.12) + 5.7\ (2.36) = 70.86 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{70.86}{51.98} = 1.364 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{5.7}{19.03} = 0.30 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 6{,}400 + 10{,}890 + 120 + 1{,}364 + 300 = 19{,}074 \text{ psi}$$

$$\sigma_\theta = 12{,}800 \text{ psi}$$

$$\sigma_r = -1{,}250 \text{ psi}$$

Section C/D

Service Level 'C' Pressure Stress:

$$\sigma_\theta = \frac{P D_i}{2t} = \frac{1,375\ (10.875)}{2\ (0.531)} = 14,080 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 7,040 \text{ psi}$$

$$\sigma_r = -1,375 \text{ psi}$$

Stress Due To Nozzle Loads:

$$P = 6.44 \text{ kip}$$

$$M = 789.3 \text{ in-kip}$$

$$F_z = 4.61 \text{ kip}$$

$$M = 789.3 + 6.44\ (7.47) + 4.61\ (0.56) = 840 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{840}{51.98} = 16.16 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{4.61}{19.03} = 0.243 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 5.08 \text{ kips}$$

$$M = 5.39 \text{ in-kips}$$

$$F_z = 6.0 \text{ kip}$$

$$M = 5.39 + 5.08\ (21.12) + 6.0\ (2.36) = 126.84 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{128.84}{51.98} = 2.44 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{6.0}{19.03} = 0.316 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 7{,}040 + 16{,}160 + 243 + 2{,}440 + 316 = 26{,}199 \text{ psi}$$

$$\sigma_\theta = 14{,}080 \text{ psi}$$

$$\sigma_r = -1{,}375 \text{ psi}$$

Section E

Design Pressure Stress:

$$\sigma_\theta = \frac{P\,D_i}{2t} = \frac{1,250\ (10.875)}{2\ (0.531)} = 12,800 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 6,400 \text{ psi}$$

$$\sigma_r = -1,250 \text{ psi}$$

Stress Due To Nozzle Loads:

$$P = 4.05 \text{ kip}$$

$$M = 534.4 \text{ in-kip}$$

$$F_z = 2.28 \text{ kip}$$

$$M = 534.4 + 4.05\ (4.72) + 2.28\ (0.56) = 554.8 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{554.8}{51.98} = 10.68 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{2.28}{19.03} = 0.12 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 2.57 \text{ kip}$$

$$M = 3.124 \text{ in-kip}$$

$$F_z = 5.7 \text{ kip}$$

$$M = 3.124 + 2.57\,(23.87) + 5.7\,(2.36) = 77.93 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{77.93}{51.98} = 1.5 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{5.7}{19.03} = 0.30 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 6{,}400 + 10{,}680 + 120 + 1{,}500 + 300 = 19{,}000 \text{ psi}$$

$$\sigma_\theta = 12{,}800 \text{ psi}$$

$$\sigma_r = -1{,}250 \text{ psi}$$

Section E

Service Level 'C' Pressure Stress:

$$\sigma_\theta = \frac{P\, D_i}{2t} = \frac{1{,}375\ (10.875)}{2\ (0.531)} = 14{,}080 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 7{,}040 \text{ psi}$$

$$\sigma_r = -1{,}375 \text{ psi}$$

Stress Due To Nozzle Loads:

$$P = 6.44 \text{ kip}$$

$$M = 789.3 \text{ in-kip}$$

$$F_z = 4.61 \text{ kip}$$

$$M = 789.3 + 6.44\ (4.72) + 4.61\ (0.56) = 822.28 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{822.28}{51.98} = 15.82 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{4.61}{19.03} = 0.243 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 5.08 \text{ kip}$$

$$M = 5.39 \text{ in-kip}$$

$$F_z = 6.0 \text{ kip}$$

$$M = 5.39 + 5.08\,(23.87) + 6.0\,(2.36) = 140.81 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{140.81}{51.98} = 2.71 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{6.0}{19.03} = 0.316 \text{ ksi}$$

Total Stress

$$\sigma_{\phi} = 7{,}040 + 15{,}820 + 243 + 2{,}710 + 316 = 26{,}129 \text{ psi}$$

$$\sigma_{\theta} = 14{,}080 \text{ psi}$$

$$\sigma_{r} = -1{,}375 \text{ psi}$$

Section F

Design Pressure Stress:

$$\sigma_\theta = \frac{P\ D_i}{2t} = \frac{1,250\ (9.794)}{2\ (0.4917)} = 12,450 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 6,225 \text{ psi}$$

$$\sigma_r = -1,250 \text{ psi}$$

Stress Due To Nozzle Loads:

$$P = 4.05 \text{ kip}$$

$$M = 534.4 \text{ in-kip}$$

$$F_z = 2.28 \text{ kip}$$

$$M = 534.4 + 4.05\ (1.62) = 541 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{541.0}{39.09} = 13.84 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{2.28}{15.89} = 0.144 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 2.57 \text{ kip}$$

$$M = 3.124 \text{ in-kip}$$

$$F_z = 5.7 \text{ kip}$$

$$M = 3.124 + 2.57\ (26.97) + 5.7\ (1.8) = 82.7 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{82.7}{39.09} = 2.12 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{5.7}{15.89} = 0.36 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 6{,}225 + 13{,}840 + 144 + 2{,}120 + 360 = 22{,}689 \text{ psi}$$

$$\sigma_\theta = 12{,}450 \text{ psi}$$

$$\sigma_r = -1{,}250 \text{ psi}$$

Section F

Service Level 'C' Pressure Stress:

$$\sigma_\theta = \frac{P\ D_i}{2t} = \frac{1,375\ (9.794)}{2\ (0.4917)} = 13,694 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 6,847 \text{ psi}$$

$$\sigma_r = -1,375 \text{ psi}$$

Stress Due To Nozzle Loads:

$$P = 6.44 \text{ kip}$$

$$M = 789.3 \text{ in-kip}$$

$$F_z = 4.61 \text{ kip}$$

$$M = 789.3 + 6.44\ (1.62) = 799.8 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{799.8}{39.09} = 20.46 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{4.61}{15.89} = 0.291 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 5.08 \text{ kips}$$

$$M = 5.39 \text{ in-kips}$$

$$F_z = 6.0 \text{ kip}$$

$$M = 5.39 + 5.08\ (26.97) + 6.0\ (1.8) = 153.2 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{153.2}{39.09} = 3.92 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{6.0}{15.89} = 0.378 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 6{,}847 + 20{,}460 + 291 + 3{,}920 + 378 = 31{,}896 \text{ psi}$$

$$\sigma_\theta = 13{,}694 \text{ psi}$$

$$\sigma_r = -1{,}375 \text{ psi}$$

Thickness Requirement of Section F

Treating the safe end as a 'Nozzle', the safe end thickness adjacent to the attaching pipe shall not be thinner than the greater of the pipe thickness or the quantity t_p S_{mp}/S_{mn}).

Where:

t_p = Pipe nominal thickness

S_{mp} = Pipe allowable (S_m)

S_{mn} = Safe End Allowable (S_m)

For our geometry:

t_p = 0.5405 in.

S_{mp} = 18.1 ksi

$t_p\ (S_{mp}/S_{mn})$ = 0.526 in

S_{mn} = 18.6 ksi

SAFE END THICKNESS = 0.5855 in.

∴ Criteria Met

Section G

Design Pressure Stress:

$$\sigma_\theta = \frac{P^*D_i}{2t} = \frac{222^* (8.505)}{2 (0.375)} = 2{,}518 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 1{,}259 \text{ psi}$$

$$\sigma_r = -222 \text{ psi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 2.57 \text{ kip}$$

$$M = 3.124 \text{ in-kip}$$

$$F_z = 5.7 \text{ kip}$$

$$M = 3.124 + 2.57 (23.87) = 64.47 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{64.47}{22.32} = 2.89 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{5.7}{10.46} = 0.545 \text{ ksi}$$

* 222 psi pressure assumed, twice normal operation

Stress Due To Nozzle Loads:

$$P = 4.05 \text{ kip}$$

$$M = 534.4 \text{ in-kip}$$

$$F_z = 2.28 \text{ kip}$$

The exact amount the safe end loads influence the thermal sleeve is unknown. However, from previous analysis it has been determined that a conservative approach is to ratio the safe end loads to correspond with the moments of inertia.

$$\frac{I_{\text{Thermal Sleeve}}}{I_{\text{Nozzle}}} = \frac{137.93}{362.33} = 0.381$$

NOTE: Corrosion not included in calculation (more conservative)

$$M = 534.4 + 4.05\ (4.72) + 2.28\ (1.8) = 557.62 \text{ in-kip}$$

$$\sigma_{\text{BEND.}} = 0.381\ \frac{M}{Z} = (0.381)\ \frac{557.62}{22.32} = 9.52 \text{ ksi}$$

$$\sigma_{\text{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{2.28}{10.46} = 0.083 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 1{,}259 + 2{,}890 + 545 + 9{,}520 + 83 = 14{,}297 \text{ psi}$$

$$\sigma_\theta = 2{,}518 \text{ psi}$$

$$\sigma_r = -222 \text{ psi}$$

Section G

Ser ' -s Level C' Pressure Stress:

$$\sigma_\theta = \frac{P*D_i}{2t} = \frac{333*(8.505)}{2\ (0.375)} = 3{,}776 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 1{,}888 \text{ psi}$$

$$\sigma_r = -333 \text{ psi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 5.08 \text{ kip}$$

$$M = 5.39 \text{ in-kip}$$

$$F_z = 6.0 \text{ kip}$$

$$M = 5.39 + 5.08\ (23.87) = 126.65 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{126.65}{22.32} = 5.675 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{6.0}{10.46} = 0.574 \text{ ksi}$$

* 333 psi pressure assumed (conservative)

Stress Due To Nozzle Loads:

$$P = 6.44 \text{ kip}$$

$$M = 789.3 \text{ in-kip}$$

$$F_z = 4.61 \text{ kip}$$

The exact amount the safe end loads influence the thermal sleeve is unknown. However, from previous analysis it has been determined that a conservative approach is to ratio the safe end loads to correspond with the moments of inertia.

$$\frac{I_{\text{Thermal Sleeve}}}{I_{\text{Nozzle}}} = \frac{137.93}{362.33} = 0.381$$

NOTE: Corrosion not included in calculation (more conservative)

$$M = 789.3 + 6.44\ (4.72) + 4.61\ (1.8) = 828.0 \text{ in-kip}$$

$$\sigma_{\text{BEND.}} = 0.381\ \frac{M}{Z} = (0.381)\ \frac{828.0}{22.32} = 14.134 \text{ ksi}$$

$$\sigma_{\text{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{4.61}{10.46} = 0.168 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 1{,}888 + 5{,}675 + 574 + 14{,}134 + 168 = 22{,}439 \text{ psi}$$

$$\sigma_\theta = 3{,}776 \text{ psi}$$

$$\sigma_r = -333 \text{ psi}$$

Section H

Design Pressure Stress:

$$\sigma_\theta = \frac{P*D_i}{2t} = \frac{222*\ (8.505)}{2\ (0.375)} = 2{,}518 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 1{,}259 \text{ psi}$$

$$\sigma_r = -222 \text{ psi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 2.57 \text{ kip}$$

$$M = 3.124 \text{ in-kip}$$

$$F_z = 5.7 \text{ kip}$$

$$M = 3.124 + 2.57\ (20.12) = 54.84 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{54.84}{22.32} = 2.46 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{5.7}{10.46} = 0.545 \text{ ksi}$$

* 222 psi pressure assumed (conservative)

Stress Due To Nozzle Loads:

$$P = 4.05 \text{ kip}$$

$$M = 534.4 \text{ in-kip}$$

$$F_z = 2.28 \text{ kip}$$

The exact amount the safe end loads influence the thermal sleeve is unknown. However, from previous analysis it has been determined that a conservative approach is to ratio the safe end loads to correspond with the moments of inertia.

$$\frac{I_{\text{Thermal Sleeve}}}{I_{\text{Nozzle}}} = \frac{137.93}{362.33} = 0.381$$

NOTE: Corrosion not included in calculation (more conservative)

$$M = 534.4 + 4.05\ (8.47) + 2.28\ (1.8) = 572.81 \text{ in-kip}$$

$$\sigma_{\text{BEND.}} = 0.381\ \frac{M}{Z} = (0.381)\ \frac{572.81}{22.32} = 9.78 \text{ ksi}$$

$$\sigma_{\text{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{2.28}{10.46} = 0.083 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 1{,}259 + 2{,}460 + 545 + 9{,}780 + 83 = 14{,}127 \text{ psi}$$

$$\sigma_\theta = 2{,}518 \text{ psi}$$

$$\sigma_r = -222 \text{ psi}$$

Section H

Service Level 'C' Pressure Stress:

$$\sigma_\theta = \frac{P*D_i}{2t} = \frac{333*(8.505)}{2\,(0.375)} = 3{,}776 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 1{,}888 \text{ psi}$$

$$\sigma_r = -333 \text{ psi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 5.08 \text{ kip}$$

$$M = 5.39 \text{ in-kip}$$

$$F_z = 6.0 \text{ kip}$$

$$M = 5.39 + 5.08\,(20.12) = 107.6 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{107.6}{22.32} = 4.821 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{6.0}{10.46} = 0.574 \text{ ksi}$$

* 333 psi pressure assumed (conservative)

Stress Due To Nozzle Loads:

$$P = 6.44 \text{ kip}$$

$$M = 789.3 \text{ in-kip}$$

$$F_z = 4.61 \text{ kip}$$

The exact amount the safe end loads influence the thermal sleeve is unknown. However, from previous analysis it has been determined that a conservative approach is to ratio the safe end loads to correspond with the moments of inertia.

$$\frac{I_{\text{Thermal Sleeve}}}{I_{\text{Nozzle}}} = \frac{137.93}{362.33} = 0.381$$

NOTE: Corrosion not included in calculation (more conservative)

$$M = 789.3 + 6.44\,(8.47) + 4.61\,(1.8) = 852.15 \text{ in-kip}$$

$$\sigma_{\text{BEND.}} = 0.381\,\frac{M}{Z} = (0.381)\,\frac{852.15}{22.32} = 14.55 \text{ ksi}$$

$$\sigma_{\text{AX.}} = 0.381\,\frac{F_z}{A} = (0.381)\,\frac{4.61}{10.46} = 0.168 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 1{,}888 + 4{,}821 + 574 + 14{,}550 + 168 = 22{,}001 \text{ psi}$$

$$\sigma_\theta = 3{,}776 \text{ psi}$$

$$\sigma_r = -333 \text{ psi}$$

Section I

Design Pressure Stress:

$$\sigma_\theta = \frac{P*D_i}{2t} = \frac{222*(8.386)}{2\ (0.494)} = 1{,}884 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 942 \text{ psi}$$

$$\sigma_r = -222 \text{ psi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 2.57 \text{ kip}$$

$$M = 3.124 \text{ in-kip}$$

$$F_z = 5.7 \text{ kip}$$

$$M = 3.124 + 2.57\ (20.12) = 54.84 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{54.84}{29.07} = 1.887 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{5.7}{13.78} = 0.414 \text{ ksi}$$

* 222 psi pressure assumed (conservative)

Stress Due To Nozzle Loads:

$$P = 4.05 \text{ kip}$$

$$M = 534.4 \text{ in-kip}$$

$$F_z = 2.28 \text{ kip}$$

The exact amount the safe end loads influence the thermal sleeve is unknown. However, from previous analysis it has been determined that a conservative approach is to ratio the safe end loads to correspond with the moments of inertia.

$$\frac{I_{\text{Thermal Sleeve}}}{I_{\text{Nozzle}}} = \frac{137.93}{362.33} = 0.381$$

NOTE: Corrosion not included in calculation (more conservative)

$$M = 534.4 + 4.05\ (8.47) + 2.28\ (1.8) = 572.81 \text{ in-kip}$$

$$\sigma_{\text{BEND.}} = 0.381\ \frac{M}{Z} = (0.381)\ \frac{572.81}{29.07} = 7.51 \text{ ksi}$$

$$\sigma_{\text{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{2.28}{13.78} = 0.063 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 942 + 1{,}887 + 414 + 7{,}510 + 63 = 10{,}816 \text{ psi}$$

$$\sigma_\theta = 1{,}884 \text{ psi}$$

$$\sigma_r = -222 \text{ psi}$$

Section I

Service Level 'C' Pressure Stress:

$$\sigma_\theta = \frac{P*D_i}{2t} = \frac{333*(8.386)}{2\ (0.494)} = 2{,}826 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 1{,}413 \text{ psi}$$

$$\sigma_r = -333 \text{ psi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 5.08 \text{ kip}$$

$$M = 5.39 \text{ in-kip}$$

$$F_z = 6.0 \text{ kip}$$

$$M = 5.39 + 5.08\ (20.12) = 107.6 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{107.6}{29.07} = 3.702 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{6.0}{13.78} = 0.436 \text{ ksi}$$

* 333 psi pressure assumed (conservative)

Stress Due To Nozzle Loads:

$$P = 6.44 \text{ kip}$$

$$M = 789.3 \text{ in-kip}$$

$$F_z = 4.61 \text{ kip}$$

The exact amount the safe end loads influence the thermal sleeve is unknown. However, from previous analysis it has been determined that a conservative approach is to ratio the safe end loads to correspond with the moments of inertia.

$$\frac{I_{\text{Thermal Sleeve}}}{I_{\text{Nozzle}}} = \frac{137.93}{362.33} = 0.381$$

NOTE: Corrosion not included in calculation (more conservative)

$$M = 789.3 + 6.44\,(8.47) + 4.61\,(1.8) = 852.15 \text{ in-kip}$$

$$\sigma_{\text{BEND.}} = 0.381\,\frac{M}{Z} = (0.381)\,\frac{852.15}{29.07} = 11.17 \text{ ksi}$$

$$\sigma_{\text{AX.}} = 0.381\,\frac{F_z}{A} = (0.381)\,\frac{4.61}{13.78} = 0.128 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 1{,}413 + 3{,}702 + 436 + 11{,}170 + 128 = 16{,}849 \text{ psi}$$

$$\sigma_\theta = 2{,}826 \text{ psi}$$

$$\sigma_r = -333 \text{ psi}$$

Section J

Design Pressure Stress:

$$\sigma_\theta = \frac{P^*D_i}{2t} = \frac{222^*\ (8.386)}{2\ (0.494)} = 1,884 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 942 \text{ psi}$$

$$\sigma_r = -222 \text{ psi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 2.57 \text{ kip}$$

$$M = 3.124 \text{ in-kip}$$

$$F_z = 5.7 \text{ kip}$$

$$M = 3.124 + 2.57\ (19.33) = 52.81 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{52.81}{29.07} = 1.82 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{5.7}{13.78} = 0.414 \text{ ksi}$$

* 222 psi pressure assumed (conservative).

Stress Due To Nozzle Loads:

$$P = 4.05 \text{ kip}$$

$$M = 534.4 \text{ in-kip}$$

$$F_z = 2.28 \text{ kip}$$

The exact amount the safe end loads influence the thermal sleeve is unknown. However, from previous analysis it has been determined that a conservative approach is to ratio the safe end loads to correspond with the moments of inertia.

$$\frac{I_{\text{Thermal Sleeve}}}{I_{\text{Nozzle}}} = \frac{137.93}{362.33} = 0.381$$

NOTE: Corrosion not included in calculation (more conservative)

$$M = 534.4 + 4.05\,(9.26) + 2.28\,(1.8) = 576.01 \text{ in-kip}$$

$$\sigma_{\text{BEND.}} = 0.381\,\frac{M}{Z} = (0.381)\,\frac{576.01}{29.07} = 7.55 \text{ ksi}$$

$$\sigma_{\text{AX.}} = 0.381\,\frac{F_z}{A} = (0.381)\,\frac{2.28}{13.78} = 0.063 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 942 + 1{,}820 + 414 + 7{,}550 + 63 = 10{,}789 \text{ psi}$$

$$\sigma_\theta = 1{,}884 \text{ psi}$$

$$\sigma_r = -222 \text{ psi}$$

Section J

Service Level 'C' Pressure Stress:

$$\sigma_\theta = \frac{P^*D_i}{2t} = \frac{333^*\ (8.386)}{2\ (0.494)} = 2,826 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 1,413 \text{ psi}$$

$$\sigma_r = -333 \text{ psi}$$

Stress Due to Thermal Sleeve Loads:

$$P = 5.08 \text{ kip}$$

$$M = 5.39 \text{ in-kip}$$

$$F_z = 6.0 \text{ kip}$$

$$M = 5.39 + 5.08\ (19.33) = 103.59 \text{ in-kip}$$

$$\sigma_{BEND.} = \frac{M}{Z} = \frac{103.59}{29.07} = 3.564 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{6.0}{13.78} = 0.436 \text{ ksi}$$

* 333 psi pressure assumed (conservative).

Stress Due To Nozzle Loads:

$$P = 6.44 \text{ kip}$$

$$M = 789.3 \text{ in-kip}$$

$$F_z = 4.61 \text{ kip}$$

The exact amount the safe end loads influence the thermal sleeve is unknown. However, from previous analysis it has been determined that a conservative approach is to ratio the safe end loads to correspond with the moments of inertia.

$$\frac{I_{\text{Thermal Sleeve}}}{I_{\text{Nozzle}}} = \frac{137.93}{362.33} = 0.381$$

NOTE: Corrosion not included in calculation (more conservative)

$$M = 789.3 + 6.44\ (9.26) + 4.61\ (1.8) = 857.24 \text{ in-kip}$$

$$\sigma_{\text{BEND.}} = 0.381\ \frac{M}{Z} = (0.381)\ \frac{857.24}{29.07} = 11.24 \text{ ksi}$$

$$\sigma_{\text{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{4.61}{13.78} = 0.128 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 1{,}413 + 3{,}564 + 436 + 11{,}240 + 128 = 16{,}781 \text{ psi}$$

$$\sigma_\theta = 2{,}826 \text{ psi}$$

$$\sigma_r = -333 \text{ psi}$$

TABLE 3-2 MAXIMUM PRIMARY STRESS INTENSITY

P_m - Primary Membrane

P_B - Primary Bending

All Stresses in ksi

Condition	Section	P_m	$P_{m\,Allow.}$ *	$P_m + P_b$	$P_m + P_b$ ** Allow.	Material
Design Event	A	14.05	26.7	20.48	40.05	SA-508 (CL.2)
	B	14.05	18.1	20.41	27.15	SA-508 (CL.1)
	C	14.05	18.1	20.33	27.15	SA-508 (CL.1)
	D	14.05	18.6	20.33	27.90	SA-350 (LF2)
	E	14.05	18.6	20.25	27.90	SA-350 (LF2)
	F	13.70	18.6	23.94	27.90	SA-350 (LF2)
	G	2.74	18.6	14.52	27.90	SA-350 (LF2)
	H	2.74	18.6	14.35	27.90	SA-350 (LF2)
	I	2.11	16.0	11.04	24.0	SA-351 (CF3)
	J	2.11	16.0	11.01	24.0	SA-351 (CF3)
Service Level 'C' Event	A	15.46	42.60	27.73	63.90	SA-508 (CL.2)
	B	15.46	27.10	27.65	40.65	SA-508 (CL.1)
	C	15.46	27.10	27.58	40.65	SA-508 (CL.1)
	D	15.46	27.85	27.58	41.77	SA-350 (LF2)
	E	15.46	27.85	27.51	41.77	SA-350 (LF2)
	F	15.07	27.85	33.28	41.77	SA-350 (LF2)
	G	4.11	27.85	22.77	41.77	SA-350 (LF2)
	H	4.11	27.85	22.33	41.77	SA-350 (LF2)
	I	3.16	19.2	17.18	28.80	SA-351 (CF3)
	J	3.16	19.2	17.11	28.80	SA-351 (CF3)

* $P_{m\,Allowable}$ is S_m for Design and the larger of 1.2 S_m or S_y for Service Level C.

** $P_m + P_{B\,Allowable}$ is 1.5 S_m for Design and the larger of 1.8 S_m or 1.5 S_y for Service Level C.

4. ANALYSIS

This section provides all the detailed thermal and stress analysis required to show an acceptable design for the operating transients imposed on the nozzle and safe end assembly.

4.1 Thermal Transient Analysis. The only feedwater nozzle thermal transient for the vessel operating conditions (Service Levels A and B) is defined in the design specification (Reference 6.1). This transient is also illustrated in Figure 4.1-1 for convenience. In order to simplify the thermal analysis, the feedwater transient was idealized as two separate transients (a heatup and cooldown). These idealized transients are illustrated in Figure 4.1-2. Notice the step change in temperatures were simulated by steep ramps. This was done to facilitate numerical convergence and results in slightly nonconservative stresses. For more detailed information on the two idealized transients, see Reference 6.1.

4.1.1 Thermal Model. The axisymmetric finite element model of the feedwater nozzle is shown in Figure 4.1.1-1. The model is made up of 2-D axisymmetric isoparametric temperature elements (STIF 55, Reference 6.3). A portion of the vessel wall was modeled as a disc for convenience of analysis since the effect of this approximation on the temperature solutions in the regions of interest is insignificant. The model ends (RPV, thermal sleeve, and safe end) are considered constant for all temperatures. The thermal properties used are as follows. Thermal properties are those of approximately 360°F.

Carbon Steel	K	=	0.03972 BTU/min in°F
	ρ	=	0.283 lb/in^3
	C_p	=	0.1226 BTU/lbm°F
Stainless Steel	K	=	0.01327 BTU/min in°F
	ρ	=	0.290 lb/in^3
	C_p	=	0.1191 BTU/lbm°F

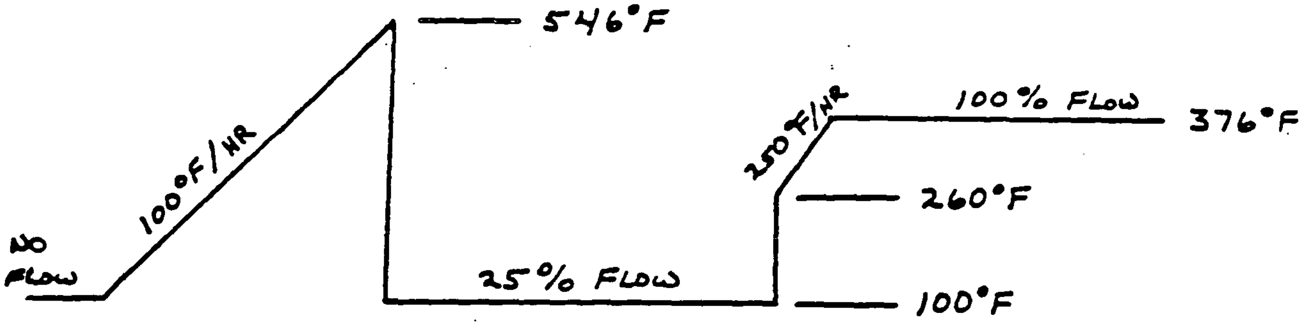


FIGURE 4.1-1 FEEDWATER THERMAL TRANSIENT (FEEDWATER TEMPERATURE VS. TIME)

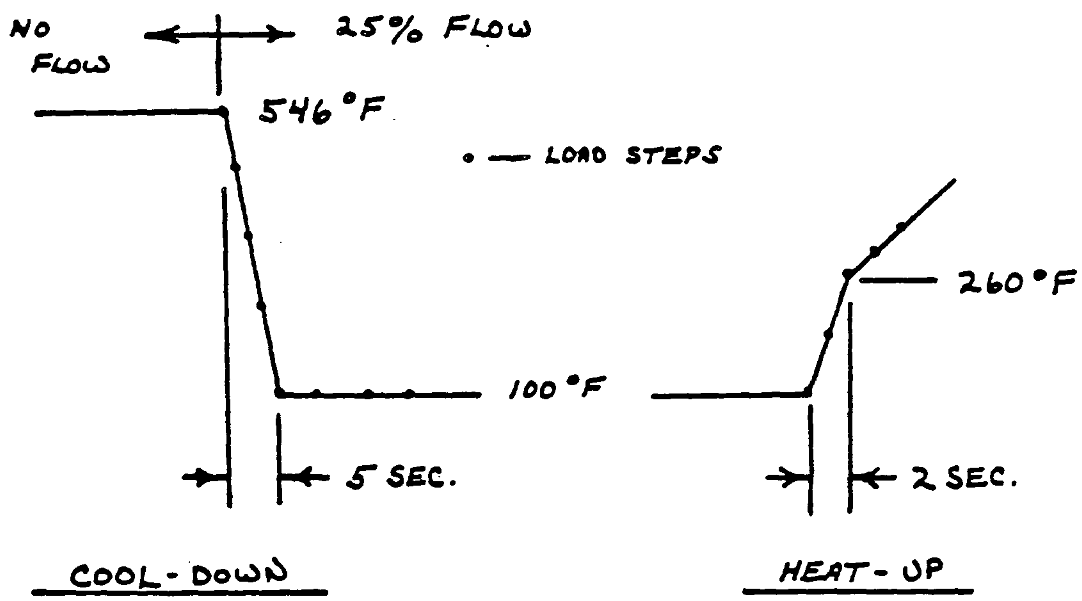


FIGURE 4.1-2 IDEALIZED THERMAL TRANSIENTS (FFEDWATER TEMPERATURE VS. TIME)

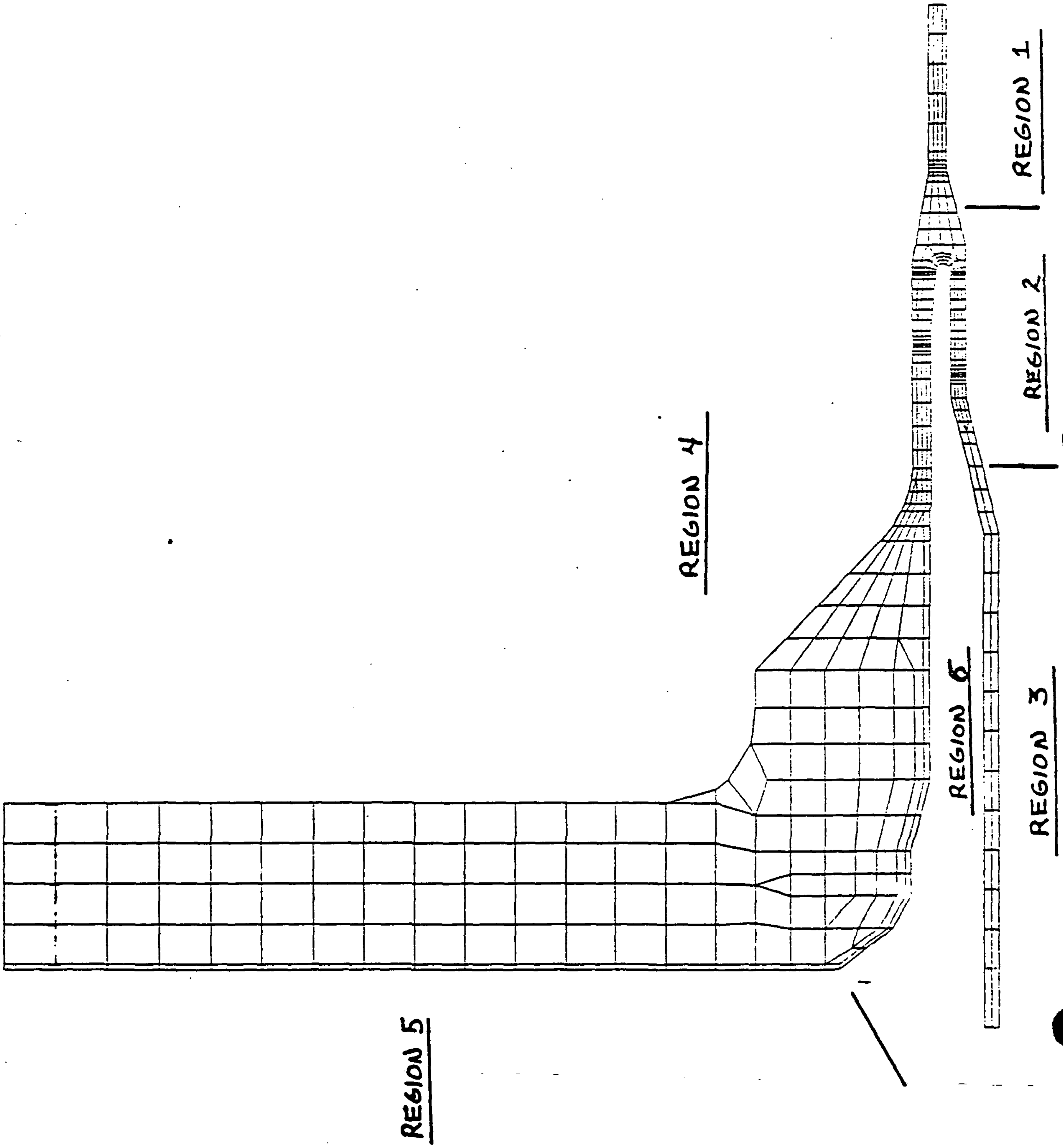


FIGURE 4.1.1-1 MONTICELLO FEEDWATER NOZZLE MODEL.

4.1.2 Feedwater Nozzle Heat Transfer Coefficients. The heat transfer coefficients were evaluated as specified in Appendix 20 of the design specification (Reference 6.1). The nozzle metal surfaces having unique film heat transfer coefficients are identified in Figure 4.1.1-1. The calculated values for each of these surfaces follow. Table 4.1.2-1 contains the water properties used at the various temperatures analysed.

4.1.2.1 Cool-Down Transient

Region 1 ID = 9.67 in. = 0.80575 ft.

No Flow Condition (Natural Convection)

For natural convection the film heat transfer equation is as follows (Reference 6.4):

$$h_f = 0.14 \frac{K}{L} (GR \quad Pr)^{1/3}$$

$$= 0.14\, K \left(\frac{\rho^2 \beta g}{\mu^2} (Pr) \right)^{1/3} \Delta T^{1/3}$$

using water properties at 350°F, and assuming a film temperature differential (ΔT) of 10°F, obtain

$$h_f = 218.44 \text{ BTU/Hr Ft}^2 \text{ °F}$$

TABLE 4.1.2-1 WATER PROPERTIES

Water Property	T (°F) 100	200	250	350	500	550
ρ $\frac{lbm}{Ft^3}$	62.0	60.1	58.8	55.6	49.0	45.9
C_p $\frac{BTU}{lbm\ ^\circ F}$	0.998	1.00	1.01	1.05	1.19	1.31
μ $\frac{lbm}{Ft\ Sec}$	0.46×10^{-3}	0.205×10^{-3}	0.158×10^{-3}	0.105×10^{-3}	0.71×10^{-4}	0.64×10^{-4}
K $\frac{BTU}{Hr\ Ft\ ^\circ F}$	0.364	0.394	0.396	0.391	0.349	0.325
P_r	4.52	1.88	1.45	1.02	0.87	0.93
β $\frac{1}{^\circ F}$	2×10^{-4}	4×10^{-4}	4.8×10^{-4}	6.9×10^{-4}	1×10^{-3}	1.1×10^{-3}
μ $\frac{lbm}{Ft\ Hr}$	1.649	0.738	0.569	0.378	0.256	0.230

(Values taken from Reference 6.4)

Where:

ρ = Density

C_p = Specific Heat

μ = Viscosity

K = Conductivity

R_e = Reynolds No. = $(DV\rho/\mu)$

V = Fluid Velocity

P_r = Prandtl No.

AND

1 gal = 0.1337 Ft^3

Forced Convection

For turbulent flow, the film heat transfer coefficient equation is as follows: (Reference 6.4):

$$h_f = 0.023 \frac{K}{D} R_e^{0.8} P_r^{0.4}$$

And for 25% flow (100% flow = 3,720 Gal/min)
(Reference 6.1)

$$V = \frac{Q}{A} = \frac{0.25(3,720)(0.1337)(4)(60)}{\pi (0.80575)^2} = 14,631 \text{ Ft/Hr}$$

At T = 550°F

$$R_e = \frac{DV\rho}{\mu} = 2.35 \times 10^6 \quad ; \quad R_e^{0.8} = 1.25 \times 10^5$$

$$P_r = 0.93 \quad ; \quad Pr^{0.4} = 0.9708$$

$$\therefore \; h_f = 1125.13 \text{ BTU/Hr Ft}^2 \text{ °F}$$

At T = 500°F

$$R_e = \frac{DV\rho}{\mu} = 2.26 \times 10^6 \quad ; \quad R_e^{0.8} = 1.211 \times 10^5$$

$$P_r = 0.87 \quad ; \quad Pr^{0.4} = 0.9465$$

$$\therefore \; h_f = 1142.23 \text{ BTU/Hr Ft}^2 \text{ °F}$$

At T = 350°F

$$R_e = \frac{DV\rho}{\mu} = 1.734 \times 10^6 \quad ; \quad R_e^{0.8} = 9.80 \times 10^4$$

$$P_r = 1.015 \quad ; \quad Pr^{0.4} = 1.006$$

$$\therefore \; h_f = 1100.4 \text{ BTU/Hr Ft}^2 \text{ °F}$$

At T = 200°F

$$R_e = \frac{DV\rho}{\mu} = 9.6 \times 10^5 \quad ; \quad R_e^{0.8} = 6.107 \times 10^4$$

$$P_r = 1.88 \quad ; \quad Pr^{0.4} = 1.2853$$

$$\therefore \; h_f = 882.84 \text{ BTU/Hr Ft}^2 \text{ °F}$$

At T = 100°F

$$R_e = \frac{DV\rho}{\mu} = 4.433 \times 10^5 \quad ; \quad R_e^{0.8} = 3.291 \times 10^4$$

$$P_r = 4.52 \quad ; \quad Pr^{0.4} = 1.828$$

$$\therefore \; h_f = 625.27 \text{ BTU/Hr Ft}^2 \text{ °F}$$

Region 2 ID = 8.38 in. = 0.69833 ft.

No Flow Condition (Natural Convection)

For natural convection, the film heat transfer equation is identical to that of Region 1. Again using water properties at 350°F and a ΔT of 10°F, obtain

$$\therefore \quad h_f = 218.44 \text{ BTU/Hr Ft}^2 \text{ °F}$$

Forced Convection

For turbulent flow, the film heat transfer equation is as follows: (Reference 6.4):

$$h_f = 0.023 \frac{K}{D} R_e^{0.8} P_r^{0.4}$$

And for 25% flow (100% flow = 3,720 Gal/min) (Reference 6.1)

$$V = \frac{Q}{A} = \frac{0.25(3,720)(0.1337)(4)(60)}{\pi (0.69833)^2} = 19,478.3 \text{ Ft/Hr}$$

At T = 550°F

$$R_e = 2.7098 \times 10^6 \; ; \quad R_e^{0.8} = 1.4007 \times 10^5$$

$$P_r^{0.4} = 0.9708$$

$$\therefore \quad h_f = 1455.6 \text{ BTU/Hr Ft}^2 \text{ °F}$$

At T = 500°F

$$R_e = 2.6076 \times 10^6 \; ; \quad R_e^{0.8} = 1.358 \times 10^5$$

$$P_r^{0.4} = 0.94648$$

$$\therefore \quad h_f = 1477.75 \text{ BTU/Hr Ft}^2 \text{ °F}$$

<u>At T = 350°F</u>

$$R_e = 2.0007 \times 10^6 \ ; \quad R_e^{0.8} = 1.0989 \times 10^5$$

$$P_r^{0.4} = 1.006$$

$$\therefore \ h_f = 1423.6 \text{ BTU/Hr Ft}^2 \text{ °F}$$

<u>At T = 200°F</u>

$$R_e = 1.1077 \times 10^6 \ ; \quad R_e^{0.8} = 6.8477 \times 10^4$$

$$P_r^{0.4} = 1.2853$$

$$\therefore \ h_f = 1142.12 \text{ BTU/Hr Ft}^2 \text{ °F}$$

<u>At T = 100°F</u>

$$R_e = 5.115 \times 10^5 \ ; \quad R_e^{0.8} = 3.6903 \times 10^4$$

$$P_r^{0.4} = 1.828$$

$$\therefore \ h_f = 808.92 \text{ BTU/Hr Ft}^2 \text{ °F}$$

Region 3 ID = 6.16 in. = 0.51333 ft.

No Flow Condition (Natural Convection)

For natural convection, the film heat transfer equation is identical to that of Region 1. Again using water properties at 350°F and a ΔT of 10°F, obtain

$$\therefore \quad h_f = 218.44 \text{ BTU/Hr Ft}^2 \text{ °F}$$

Forced Convection

For turbulent flow, the film heat transfer equation is as follows: (Reference 6.4):

$$h_f = 0.023 \left(\frac{K}{D}\right)\left(R_e\right)^{0.8}\left(P_r\right)^{0.4}$$

And for 25% flow (100% flow = 3,720 Gal/min)
(Reference 6.1)

$$V = \frac{Q}{A} = \frac{0.25(3,720)(0.1337)(4)(60)}{\pi\,(0.51333)^2} = 36,047.6 \text{ Ft/Hr}$$

At T = 550°F

$$R_e = 3.686 \times 10^6 \quad ; \quad R_e^{0.8} = 1.792 \times 10^5$$

$$P_r^{0.4} = 0.9708$$

$$\therefore \quad h_f = 2533.05 \text{ BTU/Hr Ft}^2 \text{ °F}$$

At T = 500°F

$$R_e = 3.5474 \times 10^6 \quad ; \quad R_e^{0.8} = 1.7375 \times 10^5$$

$$P_r^{0.4} = 0.9465$$

$$\therefore \quad h_f = 2571.5 \text{ BTU/Hr Ft}^2 \text{ °F}$$

At T = 350°F

$$R_e = 2.7218 \times 10^6 \; ; \quad R_e^{0.8} = 1.4057 \times 10^5$$

$$P_r^{0.4} = 1.006$$

$$\therefore \; h_f = 2477.4 \text{ BTU/Hr Ft}^2 \text{ °F}$$

At T = 200°F

$$R_e = 1.5069 \times 10^6 \; ; \quad R_e^{0.8} = 8.7594 \times 10^4$$

$$P_r^{0.4} = 1.285$$

$$\therefore \; h_f = 1987.5 \text{ BTU/Hr Ft}^2 \text{ °F}$$

At T = 100°F

$$R_e = 6.958 \times 10^5 \; ; \quad R_e^{0.8} = 4.7206 \times 10^4$$

$$P_r^{0.4} = 1.828$$

$$\therefore \; h_f = 1407.67 \text{ BTU/Hr Ft}^2 \text{ °F}$$

Region 4

As given in the design specification (Reference 6.1), the exterior surfaces are to be insulated with material having a conduction rate of 0.2 BTU/Hr Ft^2 °F. The ambient air outside the insulation is to be at least 100°F during normal operation. Therefore, for all feedwater flow and no flow conditions, use

$$h_f = 0.2 \frac{BTU}{Hr\ Ft^2\ °F}$$

Region 5

As given in Appendix 20 of the design specification (Reference 6.1), the heat transfer coefficient against the vessel wall is constant for all feedwater flow conditions.

$$h_f = 500 \frac{BTU}{Hr\ Ft^2\ °F}$$

For no feedwater flow, natural convection is the medium of heat transfer. The film heat transfer equation for natural convection is identical to that of Region 1. Using water properties of 350°F and a ΔT of 10°F, obtain

$$h_f = 218.44 \frac{BTU}{Hr\ Ft^2\ °F}$$

Region 6

Region 6 is broken up into five separate sections. This is illustrated in Figure 4.1.2-1. In addition to this, the film heat transfer coefficient on the lower surface must be adjusted to compensate for the secondary thermal sleeve which is present there. Since the temperature of the water in the annulus is given in Appendix 20 of the design specification (Reference 6.1), an equivalent heat transfer coefficient for the lower surface will be used which includes the secondary sleeve. This is illustrated in Figure 4.1.2-2.

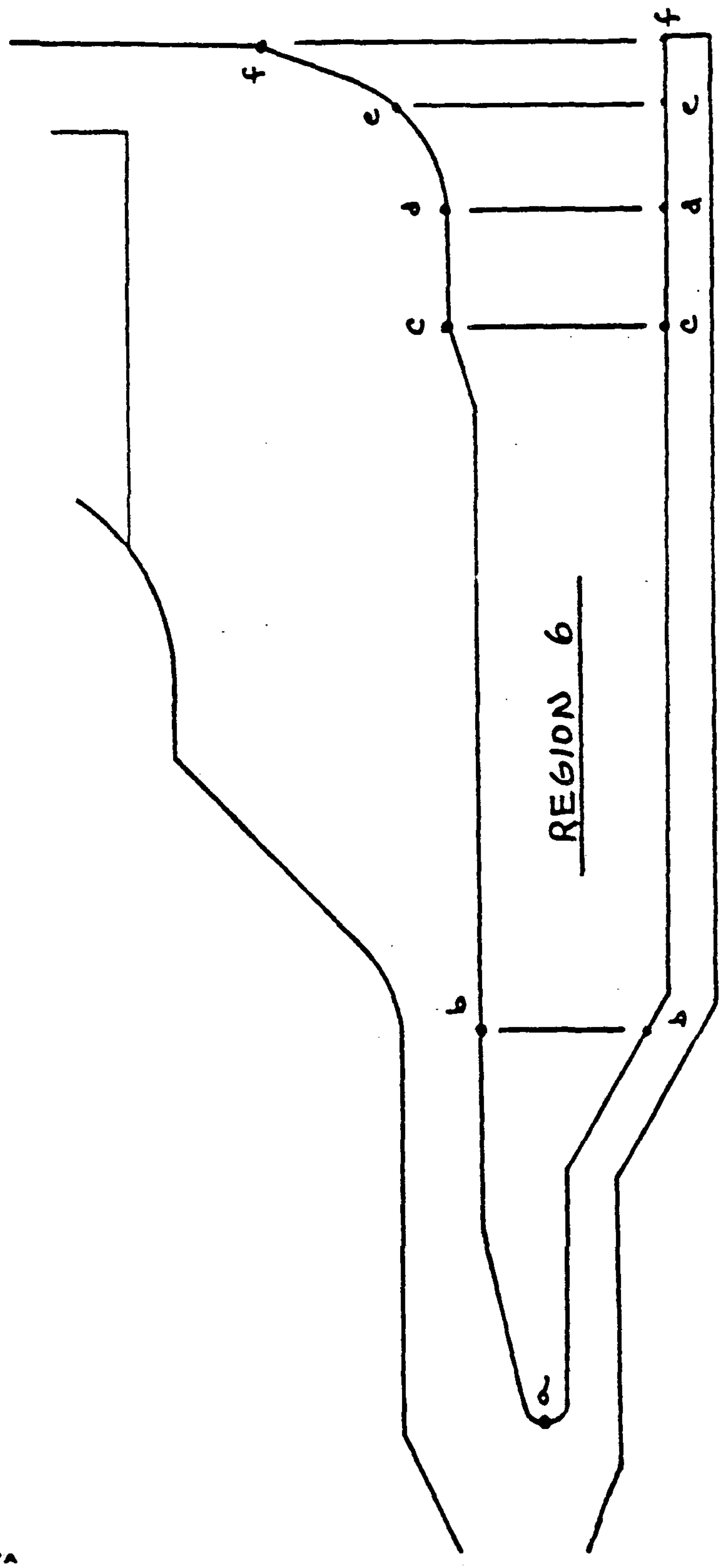


FIGURE 4.1.2-1 THE FIVE SECTIONS OF REGION 6

$$\frac{1}{h_{eq}} = \frac{1}{h_1} + \frac{1}{h_2} + \frac{1}{h_3}$$

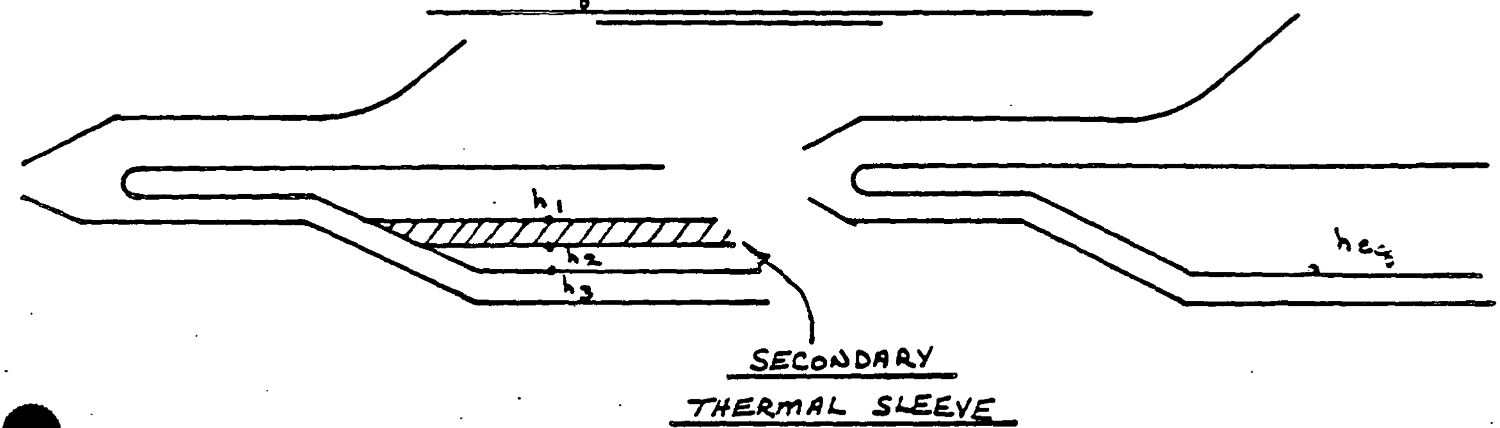


FIGURE 4.1.2-2 EQUIVALENT HEAT TRANSFER COEFFICIENT

Upper Surface

For all feedwater flows, the film heat transfer coefficient for the upper surface is given in Appendix 20 of the design specification (Reference 6.1). The coefficients given are as follows (h_f in BTU/Ft Hr^2 °F);

Section	h_f at Left End	h_f at Right End	Variation
A - B*	400	750	Linear
B - C*	750	750	Constant
C - D	750	1500	Linear
D - E	1500	1500	Constant
E - F	1500	500	Linear

Lower Surface

Since the thermal model does not include the secondary thermal sleeve, the equivalent film heat transfer coefficient for the outer surface of the primary sleeve must be found. The equivalent heat transfer analysis for the primary sleeve is made up of the following:

a. h_f of outer surface secondary sleeve (h_1)

b. h_f of inner surface secondary sleeve (h_2)

c. h_f of outer surface primary sleeve (h_3)

The conduction through the secondary sleeve will be neglected along with any conduction through the water. The three modes of heat transfer are illustrated in Figure 4.1.2-2.

* NOTE: This is different from the design specification. However, the slight difference yields higher heat transfer coefficients for these sections and thus is conservative.

Natural convection will be assumed for the annulus between the two sleeves. Therefore, from Reference 6.4, for natural convection,

$$h_f = 0.14 \left(\frac{K}{L}\right)(Gr \quad Pr)^{1/3}$$

$$= 0.14\ K \left(\frac{\rho^2\ \beta g}{\mu^2}\ (Pr)\right)^{1/3} \Delta T^{1/3}$$

using properties at T = 350°F, obtain

$$h_f = 101.39\ \Delta T^{1/3} \quad \frac{BTU}{Hr \cdot Ft^2\ °F}$$

Assuming the ΔT from the water to the thermal sleeve surface is the same for both primary and secondary sleeves, obtain

$$q = h_{eq_T}\ A\ (\Delta T_T)$$

where:

$$A = \text{surface area}$$

$$\frac{1}{h_{eq_T}} = \frac{1}{h_1} + \frac{1}{h_2} + \frac{1}{h_3}$$

$$\Delta T_T = T_{Annulus} - T_{Feedwater}$$

And

$$q = h_{eq_1},\ A\ (\Delta T_1)$$

where:

$$A = \text{surface area}$$

$$\frac{1}{h_{eq_1}} = \frac{1}{h_1} + \frac{1}{h_2}$$

$$\Delta T_1 = 2\Delta T$$

And

$$q = h_1\ A\ \Delta T$$

where:

$$A = \text{surface area}$$

Using the fact that the heat flow is constant through the heat transfer path, obtain q = constant

Therefore,

$$h_{eq_T} \, (\Delta T_T) = h_1 \, \Delta T$$

Recalling that for natural convection,

$$h_f = h_1 = h_2 = 101.4 \, \Delta T^{1/3}$$

obtain

$$\left(\frac{1}{\frac{1}{h_3} + \frac{2}{101.4 \, \Delta T^{1/3}}} \right) \left(T_{Annulus} - T_{Feedwater} \right) = 101.4 \, \Delta T^{1/3} \, (\Delta T)$$

This reduces to yield the following,

$$\frac{101.4 \, \Delta T^{4/3}}{h_3} + 2 \, \Delta T = (T_{Annulus} - T_{Feedwater})$$

This was solved by trial and error. The following is a summary of the solutions.

Feedwater Temperature	$h_3 = 750 \frac{BTU}{Ft^2 \, Hr \, °F}$	$h_3 = 1500 \frac{BTU}{Hr \, Ft^2 \, °F}$
500°F	ΔT = 18.74°F	ΔT = 19.25°F
350°F	ΔT = 73.35°F	ΔT = 82.1°F
200°F	ΔT = 124.2°F	ΔT = 141.25°F
100°F	ΔT = 156.9°F	ΔT = 179.8°F

Recalling the equation for the equivalent heat transfer coefficient, obtain

$$\frac{1}{h_{eq}} = \frac{1}{h_3} + \frac{2}{101.39 \, (\Delta T)^{1/3}}$$

The following is a summary of these equivalent heat transfer coefficient calculations.

All h's in $\frac{BTU}{Hr\ Ft^2\ °F}$

Feedwater Temperature	h_{eq} $h_3 = 750$	h_{eq} $h_3 = 1500$
500°F	114.6	124.58
350°F	165.41	192.12
200°F	189.15	224.5
100°F	200.37	240.3

Due to a calculation error in the trial and error process explained earlier, the following equivalent heat transfer coefficients were used instead of the correctly calculated values shown above.

Feedwater Temperature	h_{eq} $h_3 = 750$	h_{eq} $h_3 = 1500$
500°F	111.57	124.58
350°F	158.03	185.65
200°F	178.84	215.03
100°F	188.5	228.95

To assess this five percent difference in the coefficients, the Biot number for each pair of coefficients was compared. The comparison showed that the change in the Biot number was very small. This coupled with the fact that the portion of the thermal sleeve affected by this five percent difference is relatively far away from any highly stressed regions. Thus yielding the conclusion that the effect of this five percent difference in coefficients on the highly stressed areas, is negligible. The Biot numbers are contained in DRF (Reference 6.5).

4.1.2.2 Heat-Up Transient

Region 1

Forced Convection

For turbulent flow, the film heat transfer equation is as follows: (Reference 6.4):

$$h_f = 0.023 \left(\frac{K}{D}\right)\left(R_e^{\ 0.8}\right)\left(P_r^{\ 0.4}\right)$$

For 25 percent flow, from previous section (Paragraph 4.1.2.1),

$$V = 14{,}631 \text{ Ft/Hr}$$

and for 100 percent flow

$$V = 58{,}524.1 \text{ Ft/Hr}$$

At T = 100°F (Flow = 25 percent)

The heat transfer coefficient is identical to that calculated for the Cool-Down transient (Paragraph 4.1.2.1)

$$\therefore \ h_f = 625.27 \ \frac{\text{BTU}}{\text{Hr Ft}^2 \ ^\circ\text{F}}$$

At T = 180°F (Flow = 25 percent)

Will assume the heat transfer coefficient to be identical to that calculated at 200°F in the Cool-down section.

$$\therefore \ h_f = 882.84 \ \frac{\text{BTU}}{\text{Hr Ft}^2 \ ^\circ\text{F}}$$

<u>At T = 260°F</u> (Flow = 25 percent)

$$R_e = 1.2187 \times 10^6 \quad ; \quad R_e^{0.8} = 7.3912 \times 10^4$$

$$P_r^{0.4} = 1.1605$$

$$\therefore \quad h_f = 969.55 \frac{\text{BTU}}{\text{Hr Ft}^2 \text{ °F}}$$

<u>At T = 376°F</u> (Flow = 100 percent)

$$R_e = 6.936 \times 10^6 \quad ; \quad R_e^{0.8} = 2.9709 \times 10^5$$

$$P_r^{0.4} = 1.006$$

$$\therefore \quad h_f = 3335.8 \frac{\text{BTU}}{\text{Hr Ft}^2 \text{ °F}}$$

Region 2 ID = 8.38 in. = 0.69833 Ft.

Forced Convection

For turbulent flow, the film heat transfer equation is as follows: (Reference 6.4):

$$h_f = 0.023 \left(\frac{K}{D}\right)\left(R_e^{0.8}\right)\left(P_r^{0.4}\right).$$

For 25 percent flow, from previous section (Paragraph 4.1.2.1),

$$V = 19{,}478.3 \text{ Ft/Hr}$$

and for 100 percent flow

$$V = 77{,}913.8 \text{ Ft/Hr}$$

At T = 100°F (Flow = 25 percent)

The heat transfer coefficient is identical to that calculated for the Cool-Down transient (Paragraph 4.1.2.1)

$$\therefore \; h_f = 808.92 \; \frac{\text{BTU}}{\text{Hr Ft}^2 \; °\text{F}}$$

At T = 180°F (Flow = 25 percent)

Will assume the heat transfer coefficient to be identical to that calculated at 200°F in the Cool-down section. (Paragraph 4.1.2.1)

$$\therefore \; h_f = 1142.12 \; \frac{\text{BTU}}{\text{Hr Ft}^2 \; °\text{F}}$$

<u>At T = 260°F</u> (Flow = 25 percent)

$$R_e = 1.406 \times 10^6 \quad ; \quad R_e^{0.8} = 8.2875 \times 10^4$$

$$P_r^{0.4} = 1.1605$$

$$\therefore \; h_f = 1254.4 \frac{\text{BTU}}{\text{Hr Ft}^2 \text{ °F}}$$

<u>At T = 376°F</u> (Flow = 100 percent)

$$R_e = 8.0 \times 10^6 \quad ; \quad R_e^{0.8} = 3.33 \times 10^5$$

$$P_r^{0.4} = 1.006$$

$$\therefore \; h_f = 4315.7 \frac{\text{BTU}}{\text{Hr Ft}^2 \text{ °F}}$$

Region 3 ID = 6.16 in. = 0.51333 Ft.

Forced Convection

For turbulent flow, the film heat transfer equation is as follows: (Reference 6.4):

$$h_f = 0.023 \left(\frac{K}{D}\right)\left(R_e^{0.8}\right)\left(P_r^{0.4}\right)$$

For 25 percent flow, from previous section (Paragraph 4.1.2.1),

$$V = 36{,}047.7 \text{ Ft/Hr}$$

and for 100 percent flow

$$V = 144{,}190.7 \text{ Ft/Hr}$$

At T = 100°F (Flow = 25 percent)

The heat transfer coefficient is identical to that calculated for the Cool-Down transient (Paragraph 4.1.2.1)

$$\therefore \; h_f = 1407.67 \frac{\text{BTU}}{\text{Hr Ft}^2 \; °\text{F}}$$

At T = 180°F (Flow = 25 percent)

Will assume the heat transfer coefficient to be identical to that calculated at 200°F in the Cool-down section (Paragraph 4.1.2.1).

$$\therefore \; h_f = 1987.5 \frac{\text{BTU}}{\text{Hr Ft}^2 \; °\text{F}}$$

At T = 260°F (Flow = 25 percent)

$$R_e = 1.913 \times 10^6 \quad ; \quad R_e^{0.8} = 1.06 \times 10^5$$

$$P_r^{0.4} = 1.1605$$

$$\therefore \quad h_f = 2182.85 \frac{BTU}{Hr\ Ft^2\ °F}$$

At T = 376°F (Flow = 100 percent)

$$R_e = 1.0887 \times 10^6 \quad ; \quad R_e^{0.8} = 4.261 \times 10^5$$

$$P_r^{0.4} = 1.006$$

$$\therefore \quad h_f = 7509.98 \frac{BTU}{Hr\ Ft^2\ °F}$$

Region 4

As given in the design specification (Reference 6.1), the exterior surfaces are to be insulated with material having a conduction rate of $0.2 \frac{BTU}{Hr\ Ft^2\ °F}$

$$\therefore h_f = 0.2 \frac{BTU}{Hr\ Ft^2\ °F}$$

Region 5

As given in the design specification (Reference 6.1), the heat transfer coefficient against the vessel wall is constant for all feedwater flow conditions.

$$h_f = 500 \frac{BTU}{Hr\ Ft^2\ °F}$$

Region 6

The analysis of Region 6 here follows the same procedure of the analysis of Region 6 during the cool down transient (Paragraph 4.1.2.1). Refer to Paragraph 4.1.2.1 for greater details.

Upper Surface

For all feedwater flows, the film heat transfer coefficient for the upper surface is given in Appendix 20 of the design specification (Reference 6.1). They are listed in Paragraph 4.1.2.1.

Lower Surfaces

The procedure used is identical to that of Paragraph 4.1.2.1. For more details, refer to Paragraph 4.1.2.1.

The following equation must be solved by trial and error to obtain the ΔT across the thermal sleeve.

$$\frac{101.4\ \Delta T^{4/3}}{h_3} + 2\ \Delta T = (T_{Annulus} - T_{Feedwater})$$

The following is a summary of the solutions.

Feedwater Temperature	$h_3 = 750 \frac{BTU}{Ft^2\ Hr\ °F}$	$h_3 = 1500 \frac{BTU}{Hr\ Ft^2\ °F}$
100°F	ΔT = 157°F	ΔT = 180°F
180°F	ΔT = 131°F	ΔT = 149°F
260°F	ΔT = 104°F	ΔT = 117.7°F
376°F	ΔT = 58°F	ΔT = 64.5°F

Recalling the equation for the equivalent heat transfer coefficient, obtain

$$\frac{1}{h_{eq}} = \frac{1}{h_3} + \frac{2}{101.39\ (\Delta T)^{1/3}}$$

The following is a summary of these equivalent heat transfer coefficient calculations.

All h's in $\frac{BTU}{Hr\ Ft^2\ °F}$

Feedwater Temperature	h_{eq} h_3 = 750	h_3 = 1500
100°F	200.4	240.4
180°F	191.7	228.0
260°F	180.9	213.14
376°F	155.5	179.04

4.1.2.3 Normal Operation. The heat transfer coefficients used for the normal operation run are the same as those given during the heat up transient (Paragraph 4.1.2.2) when T = 376°F.

4.1.3 Feedwater Nozzle Annulus Fluid Temperature. Appendix 20 of the design specification (Reference 6.1), defines the annulus fluid temperatures for all conditions. For completeness it is repeated below.

$$T = T_{FW} + C\,(T_A - T_{FW})$$

Where:

T = Annulus fluid temperature

T_{FW} = Feedwater fluid temperature

T_A = Region A fluid temperature = 546°F

C = Coefficient defined by table below

	Points				
Feedwater Flow	a	b	c	d + e	f
25%	0.70	0.92	0.96	0.96	0.96
100%	0.68	0.83	0.86	0.86	0.90

Use the above values of C for all cases with feedwater flow. Use C = 1.0 when no feedwater flow. Use C = 1.0 downstream of f for all feedwater flows. Interpolate linearly between defined points; see Figure 4.1.2-1 for point locations.

4.1.4 Thermal Analysis Results. By applying the boundary conditions (heat transfer coefficients and flow temperatures), a transient heat transfer analysis was performed using the finite element program ANSYS (Reference 6.3) for the thermal transients described earlier. During these transients, the isolated face of the disc in the finite element model was maintained at a constant vessel temperature of 546°F to simulate the vessel as a heat source. The temperature solutions obtained for the various times of the transients were saved on tape for later use in the thermal stress analysis. Some of the isotherm plots obtained for various times of the transients are shown in Figures 4.1.4-1 through 4.1.4-7.

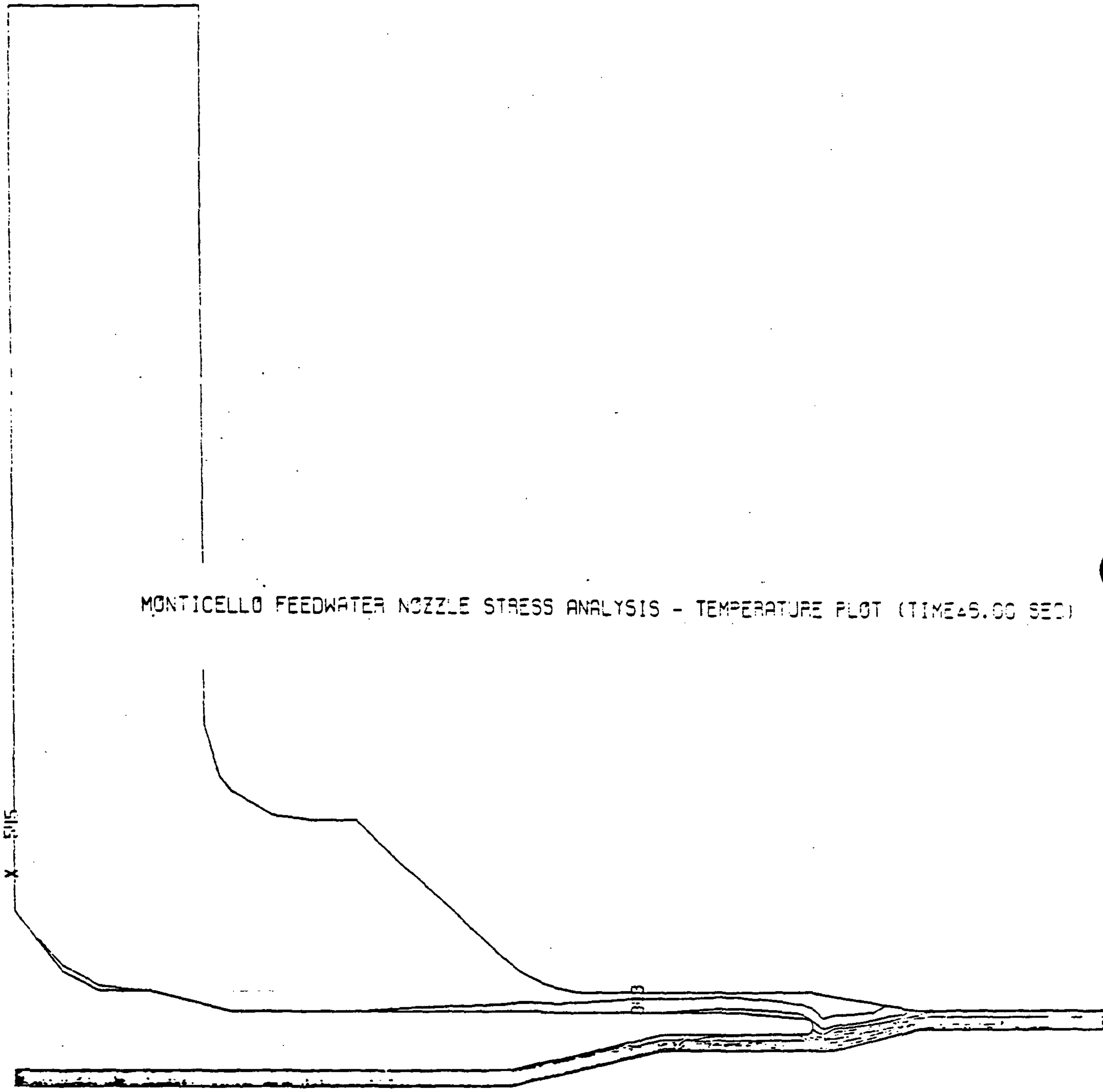


FIGURE 4.1.4-1 COOLDOWN TRANSIENT

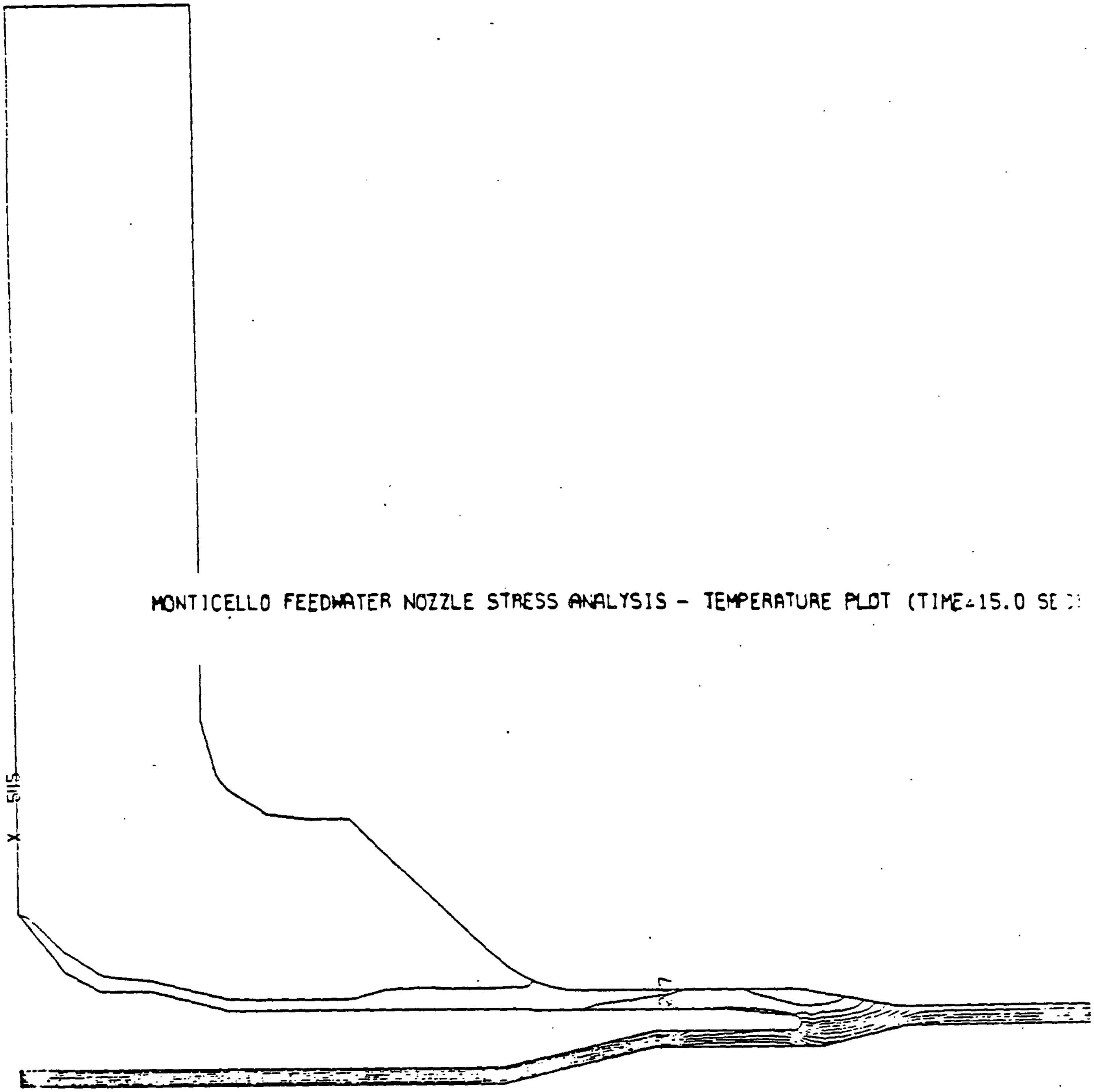


FIGURE 4.1.4-2 COOLDOWN TRANSIENT

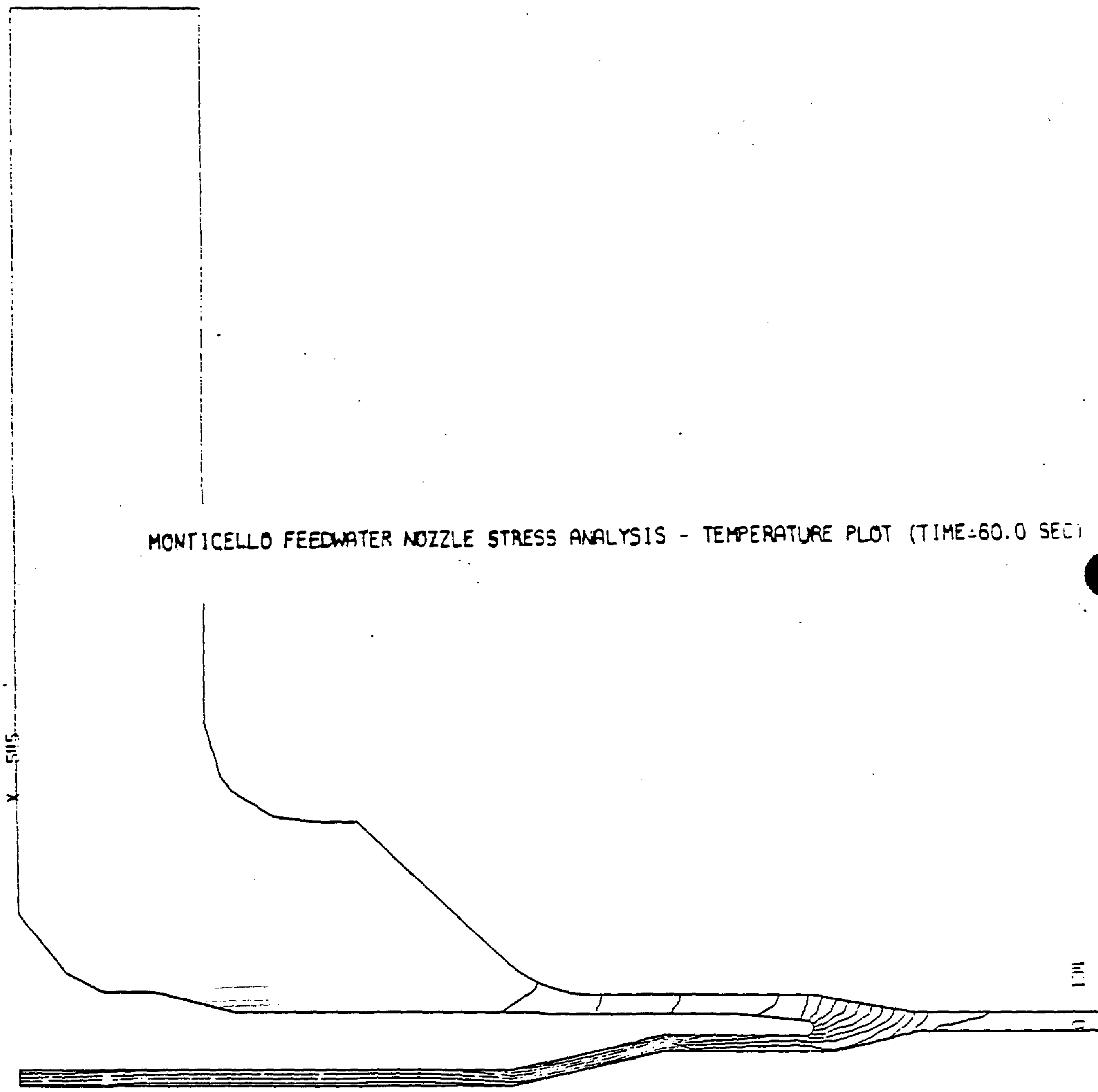


FIGURE 4.1.4-3 COOLDOWN TRANSIENT

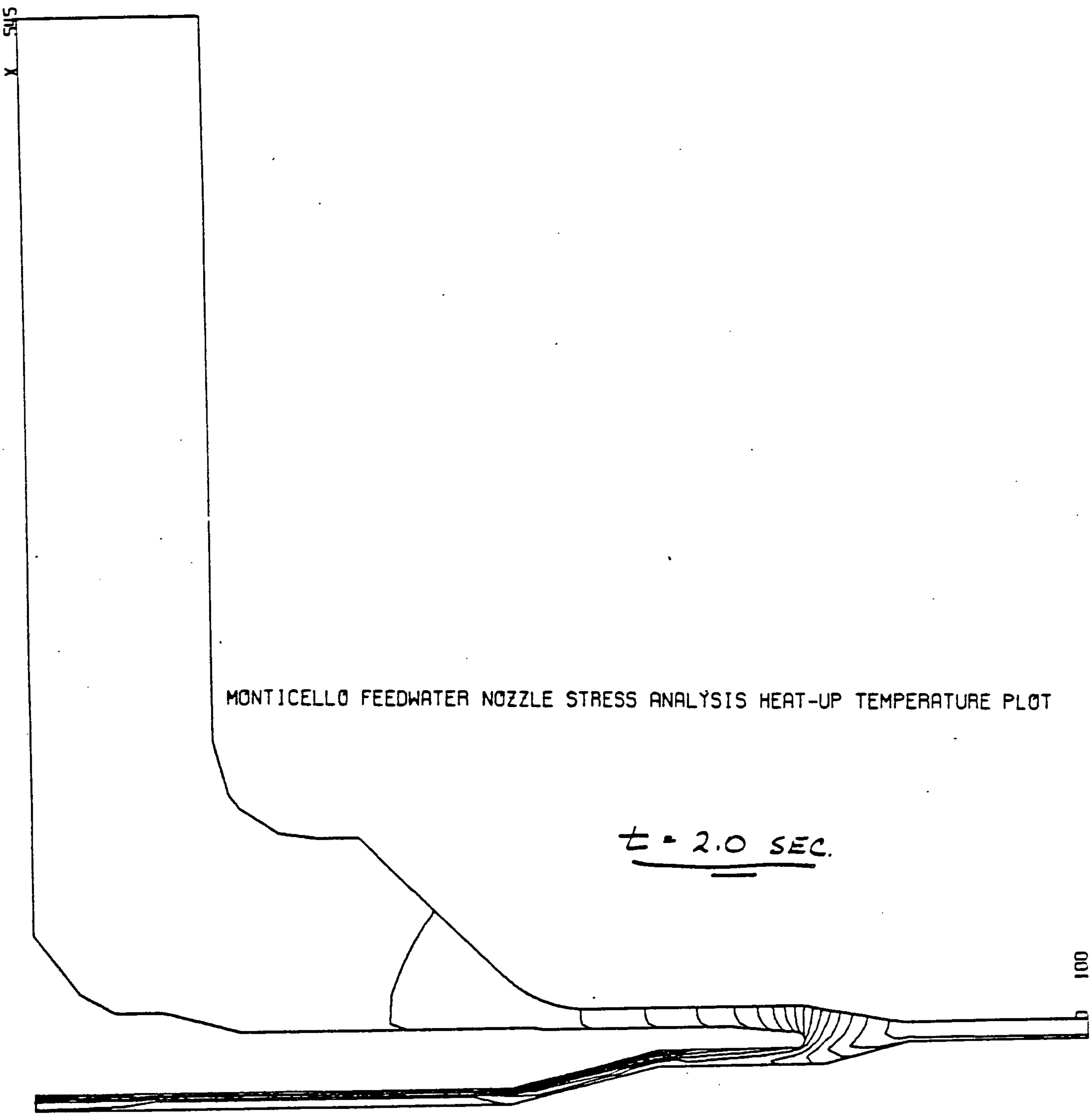

545
X
MONTICELLO FEEDWATER NOZZLE STRESS ANALYSIS HEAT-UP TEMPERATURE PLOT
t = 2.0 SEC.
100

FIGURE 4.1.4-4

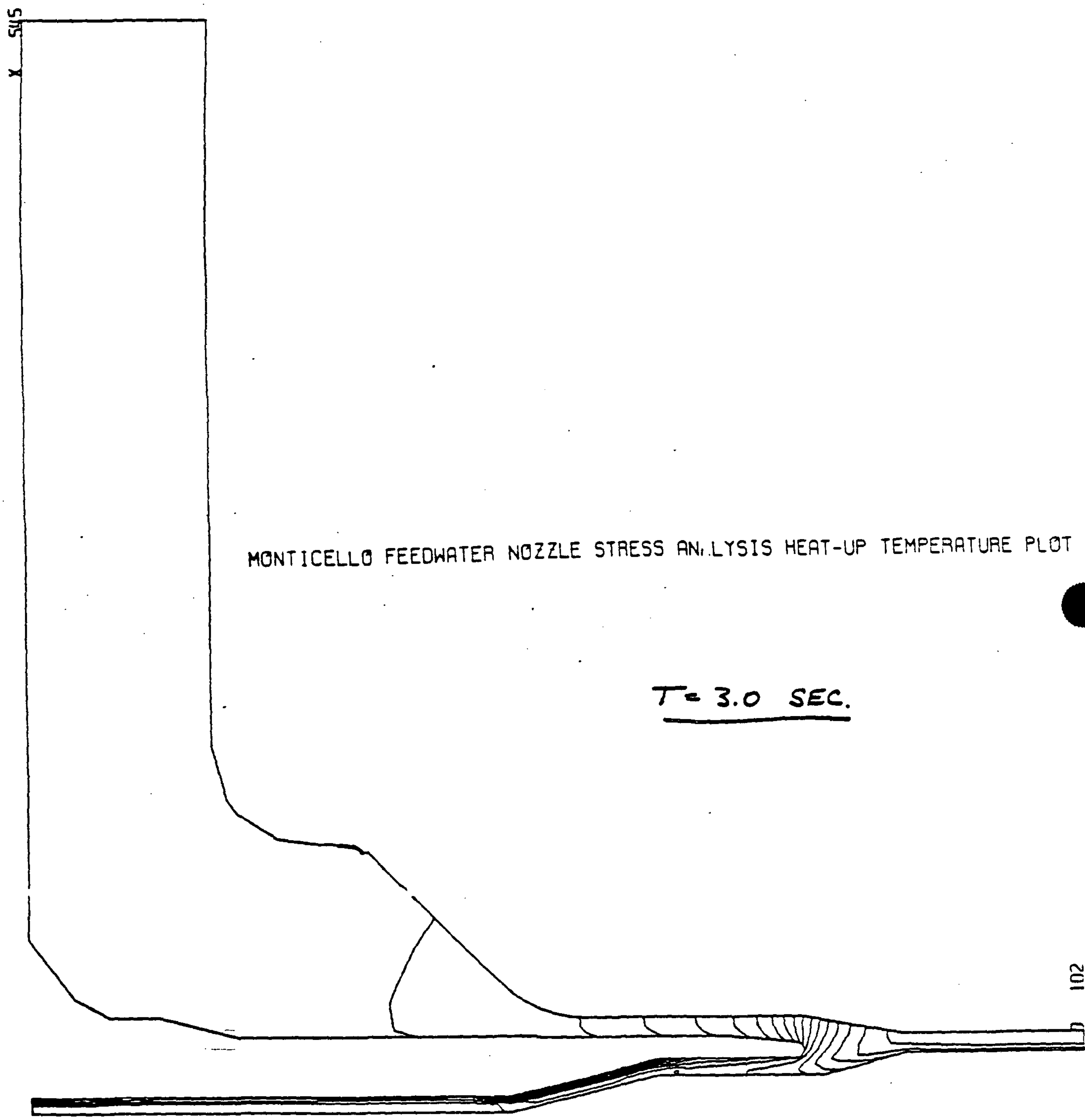

545
X
MONTICELLO FEEDWATER NOZZLE STRESS AN..LYSIS HEAT-UP TEMPERATURE PLOT
T= 3.0 SEC.
102

FIGURE 4.1.4-5

MONTICELLO FEEDWATER NOZZLE STRESS ANALYSIS HEAT-UP TEMPERATURE PLOT

t = 12.0 SEC.

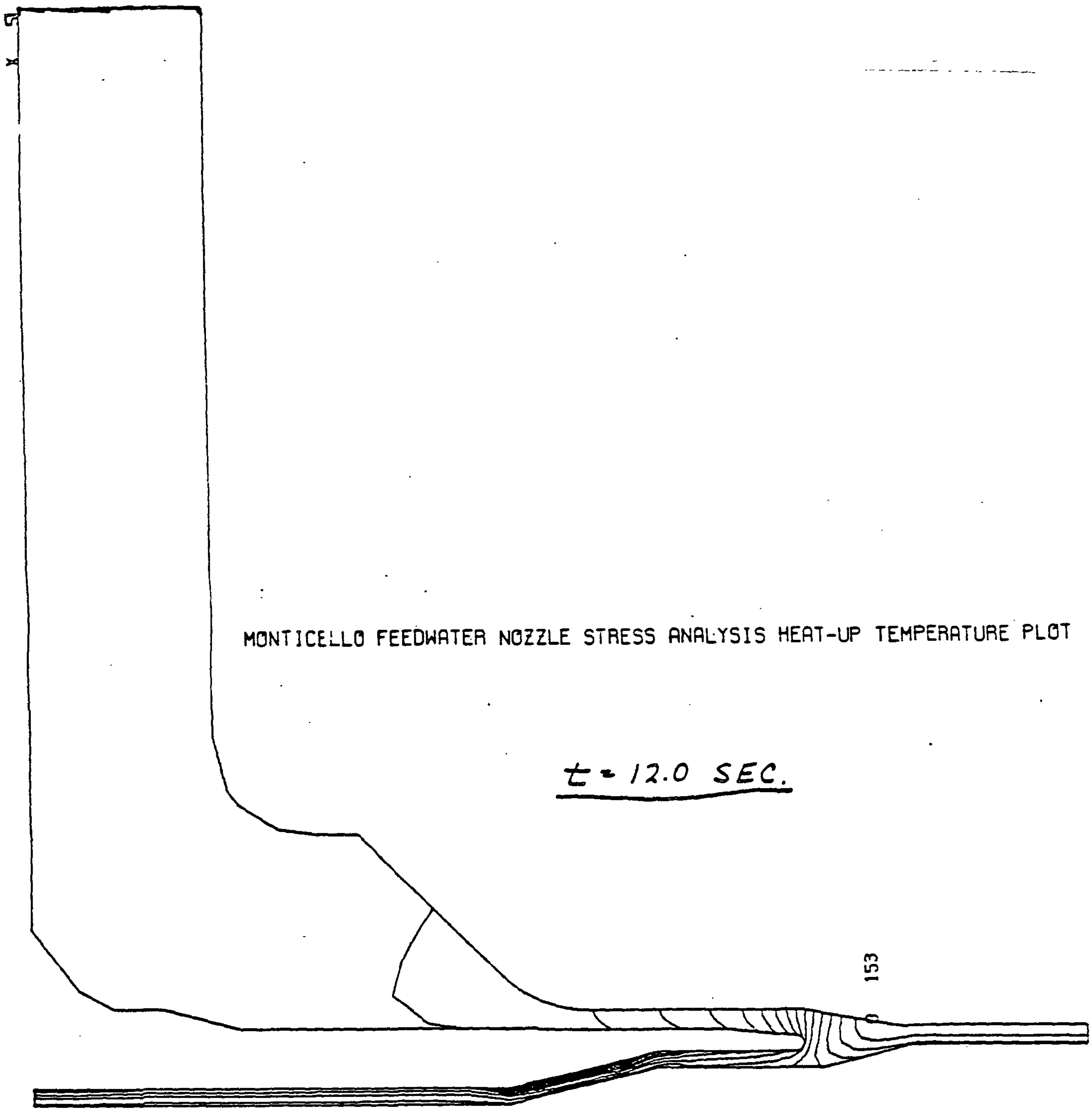


FIGURE 4.1.4-6

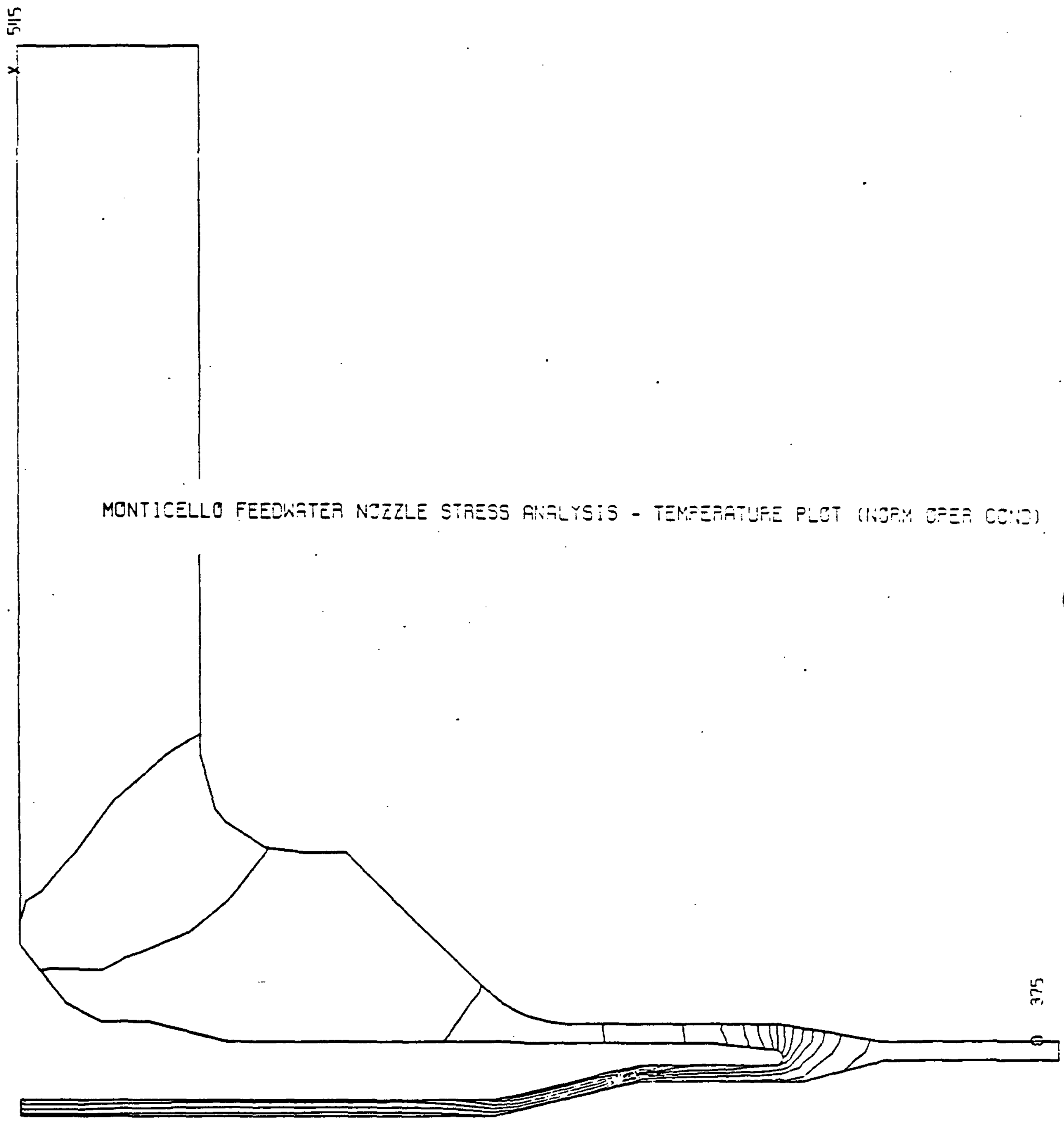
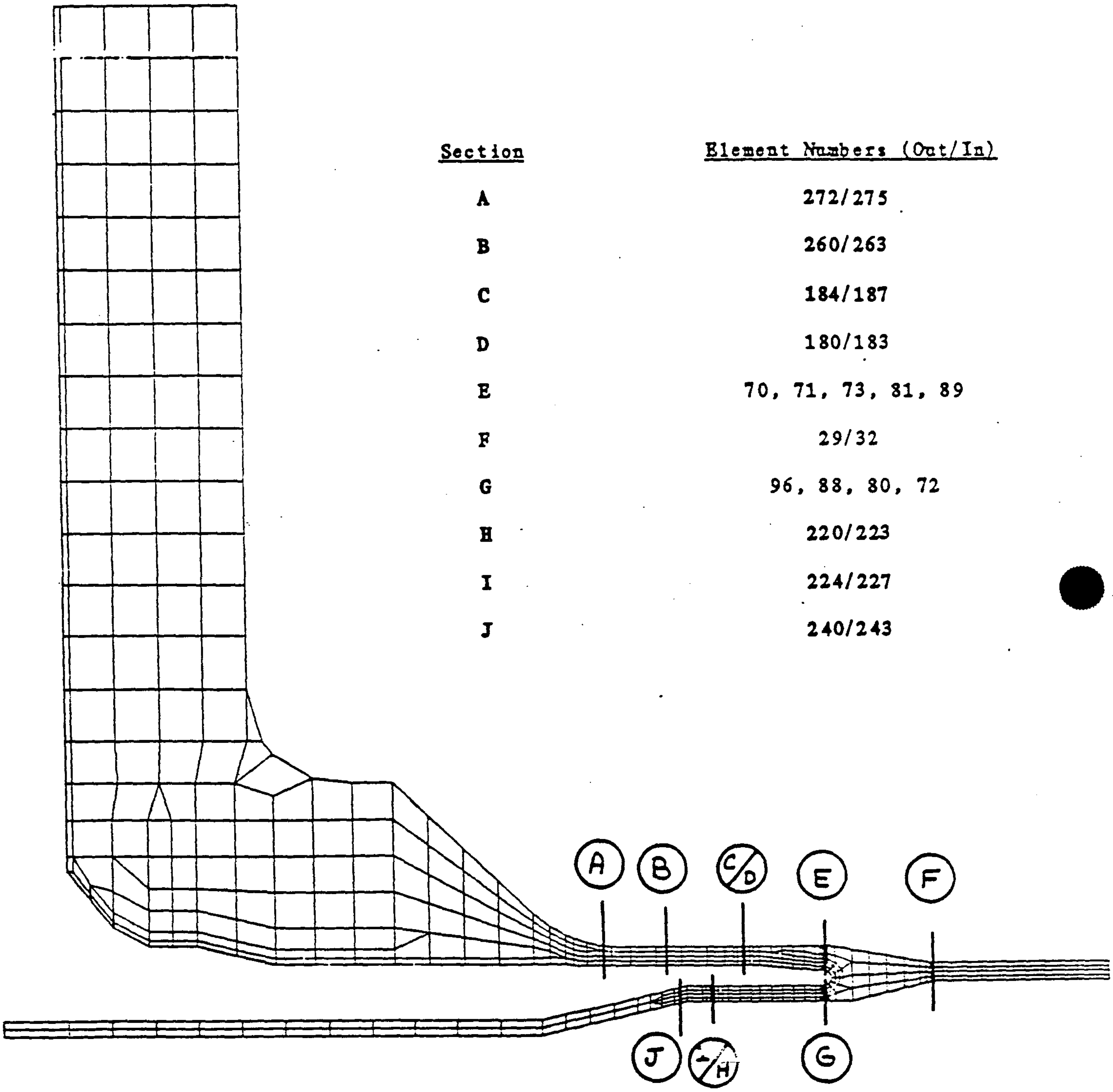

515
MONTICELLO FEEDWATER NOZZLE STRESS ANALYSIS - TEMPERATURE PLOT (NORM OPER COND)
375

FIGURE 4.1.4-7

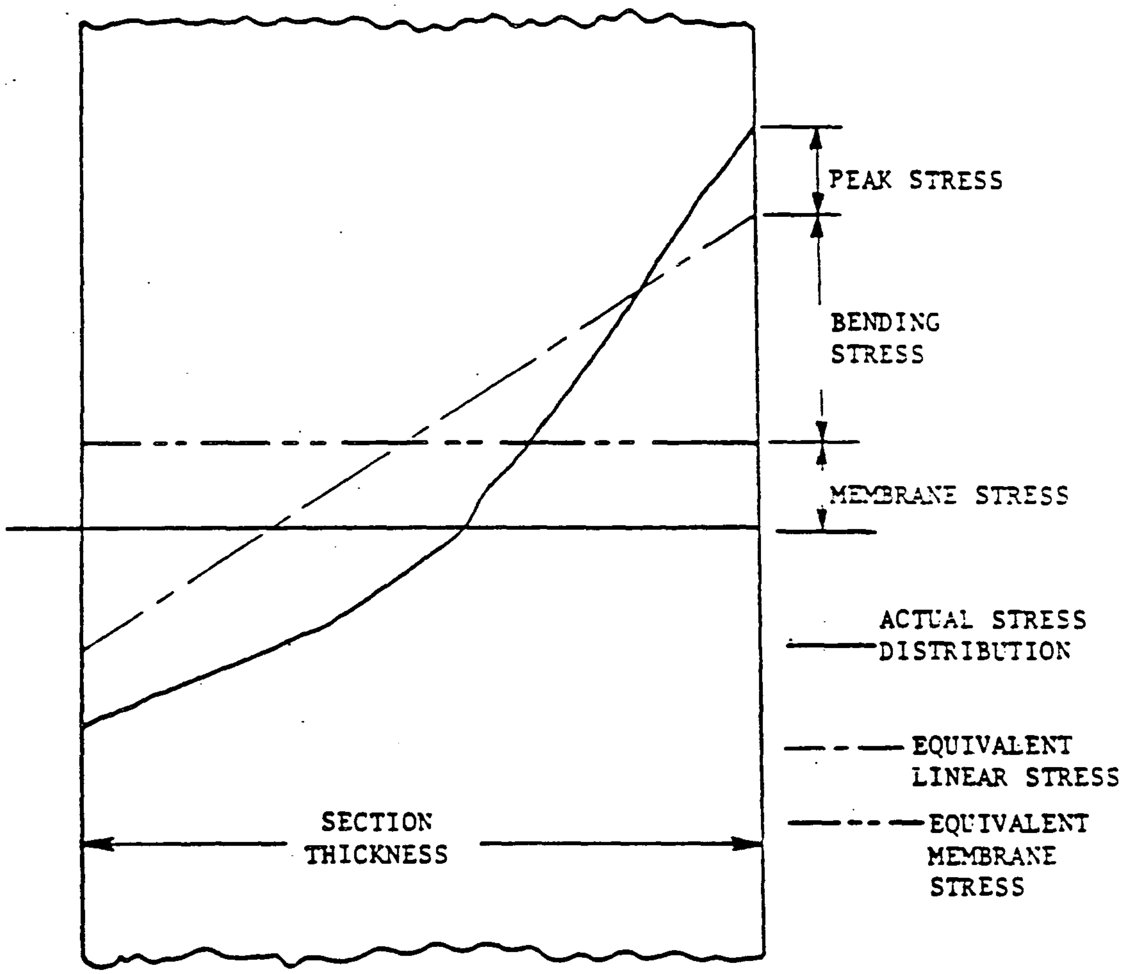
4.2 Stress Analysis. The stress analysis is broken into three separate areas: thermal stresses, mechanical load stresses, and pressure stresses. The stress intensities for these three cases are then summed up to yield the total primary plus secondary stress intensity. A fatigue analysis is then performed to obtain the fatigue usage factor for the system.

4.2.1 Selected Locations for Stress Evaluation. The sections shown in Figure 4.2.1-1 are the locations selected for stress evaluation. Finite element stresses are integrated across each section to determine the equivalent membrane, bending, and peak stresses. This was done by averaging the stress across the section and linearizing the stress distribution through the section thickness as shown in Figure 4.2.1-2. These calculations were performed using an engineering aid computer program 'NONO'. A listing of this program is included in Appendix 10.



Section	Element Numbers (Out/In)
A	272/275
B	260/263
C	184/187
D	180/183
E	70, 71, 73, 81, 89
F	29/32
G	96, 88, 80, 72
H	220/223
I	224/227
J	240/243

FIGURE 4.2.1-1 LOCATIONS FOR EVALUATING STRESSES



LINEARIZATION OF STRESS DISTRIBUTION ACROSS A SECTION THICKNESS

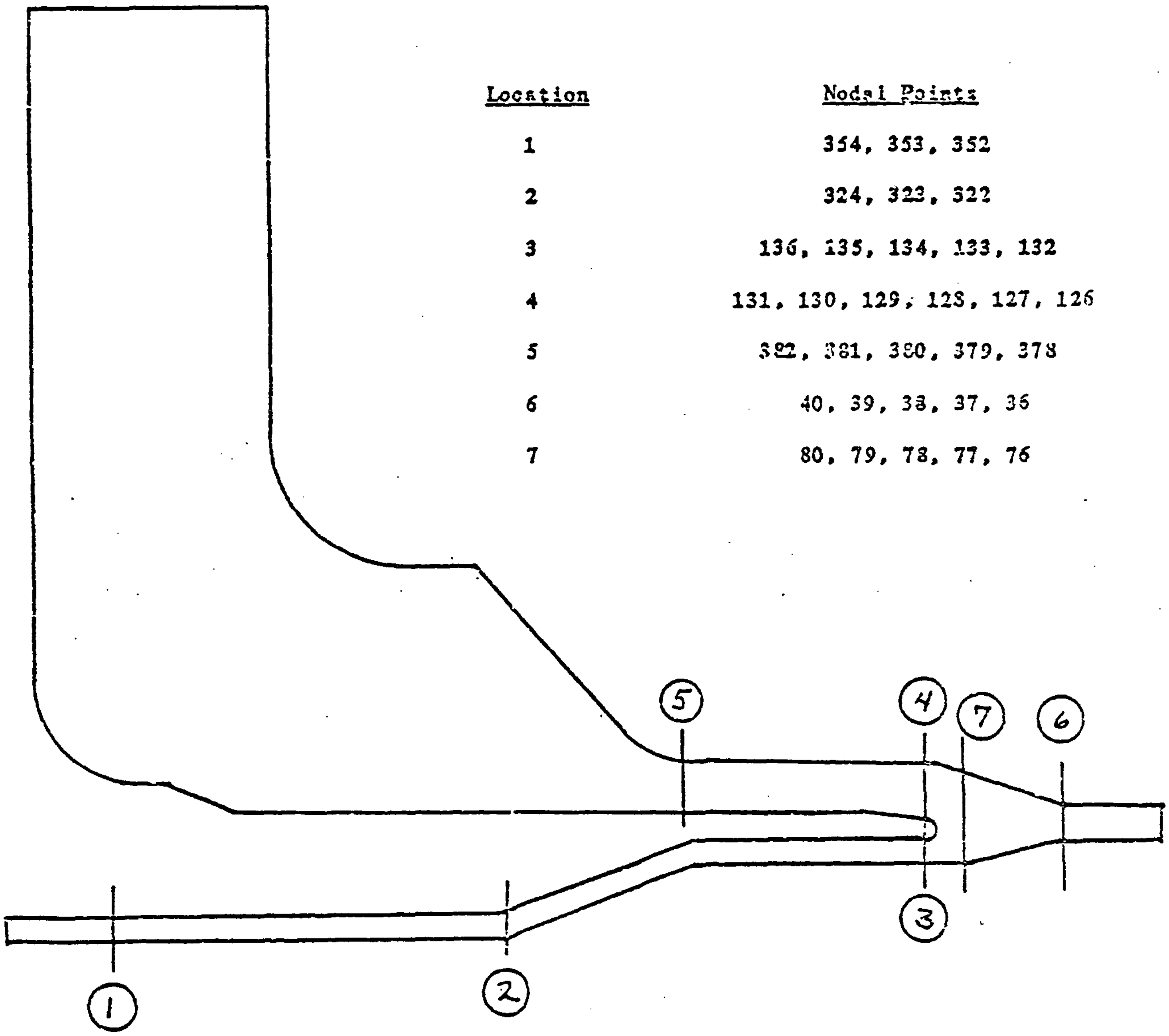
FIGURE 4.2.1-2 LINEARIZATION OF STRESS DISTRIBUTION ACROSS A SECTION THICKNESS

4.2.2 Thermal Stress Analysis. The thermal stresses were obtained using the finite element computer program ANSYS. The same finite element model used for the thermal transient analysis (Figure 4.1.1-1) was also used for the thermal stress analysis. However, instead of temperature elements being used, 2-D axisymmetric isoparametric stress elements (STIF-42, Reference 6.3) were used. The modeling of the portion of the vessel wall as a disc is a conservative assumption for the thermal stress solutions since the inplane radial stiffness of a disc is higher than that of a shell. The applied boundary condition at the isolated surfaces of the vessel, safe end, and thermal sleeve is the generalized plane strain condition. The elastic properties used were considered constant for all temperatures. These properties are:

Carbon Steel	$E = 27.2 \times 10^6$ psi
	$\alpha = 7.33 \times 10^{-6}$ in./in.
	$= 0.3$
	$\rho = 0.283$ lbf/in.^{3}
Stainless Steel	$E = 26.85 \times 10^6$ psi
	$\alpha = 9.87 \times 10^{-6}$ in./in.
	$= 0.3$
	$\rho = 0.29$ lbf/in.^{3}
Vessel Steel	$E = 28.8 \times 10^6$ psi
	$\alpha = 7.33 \times 10^{-6}$ in./in.
	$= 0.3$
	$\rho = 0.283$ lbf/in.^{3}

4.2.2.1 Selection of Times for Stress Evaluation. The times in the transients considered important for subsequent thermal stress evaluation are determined by a review of temperature differences between selected nodes of the thermal model. This process is performed for the cool down transient. Figure 4.2.2.1-1 illustrates the selected nodal points and Table 4.2.2.1-1 contains the temperature information. Actual temperatures are in DRF B13-909 (Reference 6.5).

4.2.2.2 Thermal Stress Analysis Results. The thermal transient stresses were evaluated at the indicated times of the transients. The thermal membrane plus bending stresses for each of the previously noted transient times are tabulated in Tables 4.2-1 through 4.2-9. The thermal membrane plus bending plus peak stresses for each of the previously noted transient times are tabulated in Tables 4.2-10 through 4.2-18.



Location	Nodal Points
1	354, 353, 352
2	324, 323, 322
3	136, 135, 134, 133, 132
4	131, 130, 129, 128, 127, 126
5	382, 381, 380, 379, 378
6	40, 39, 38, 37, 36
7	80, 79, 78, 77, 76

FIGURE 4.2.2.1-1 LOCATIONS USED FOR EVALUATING TEMPERATURE DIFFERENCE

TABLE 4.2.2.1-1 TEMPERATURE DIFFERENCES FOR COOL DOWN TRANSIENT

Load Step	Time (Minutes)	$T_7 - T_6$	$T_7 - T_3$	ΔT_7	ΔT_3	ΔT_4
6	0.10	59	99	205	129	30
7	0.1167	69	117	220	128	33
8	0.1333	78	130	232	125	34
9	0.150	84	141	250	122	36
10	0.1667	90	149	265	120	36
11	0.2083	102	163	274	115	36
12	0.250	111	169	281	111	36
13	0.333	128	172	269		36
14	0.50	147	156	235		32
15	0.750	158	122	204		24
16	1.00	156	94			
17	2.00	127				
18	3.00	112				

(All ΔT's in °F)

DRF B13-909 contains actual nodal temperature data (Reference 6.5)

Times Selected	Load Step	Time (Minutes)
	6	0.10
	12	0.25
	16	1.00
	23	Steady State

4.2.3 Mechanical Load Stress Analysis. The mechanical load stresses were obtained by using the procedure followed in Paragraph 3 to obtain the design stresses. The only variation is in obtaining the applied loading (however, this will be investigated in the following Paragraph). For completeness, the calculations are presented in this report in Paragraph 4.2.3.2.

4.2.3.1 Applied Mechanical Loading. To obtain the largest load ranges, the loadings given in Section 3 are used. Note that in load range calculations, dead weight loads are not included. These loads simply cancel out.

Nozzle Loading

$$P = (F_x^2 + F_y^2)^{1/2}$$

$$M = (M_x^2 + M_y^2 + M_z^2)^{1/2}$$

'A' Nozzle Loading (Service Level 'B')

Static

$$P = (0.02^2 + 0.16^2)^{1/2} = 0.161$$

$$M = (12.0^2 + 12.1^2 + 45.0^2)^{1/2} = 48.12$$

$$F_z = 0.21$$

Dynamic

$$P = (0.29^2 + 2.51^2)^{1/2} = 2.53$$

$$M = (9.3^2 + 158.9^2 + 313.4^2)^{1/2} = 351.5$$

$$F_z = 2.23$$

'B' Nozzle Loading (Service Level 'B')

Static

$$P = (0.82^2 + 4.34^2)^{1/2} = 4.42$$

$$M = (267.2^2 + 66.7^2 + 1.4^2)^{1/2} = 275.4$$

$$F_z = 1.37$$

Dynamic

$$P = (2.44^2 + 1.97^2)^{1/2} = 3.136$$

$$M = (376^2 + 106.3^2 + 10.6^2)^{1/2} = 390.2$$

$$F_z = 0.26$$

Thermal Sleeve Loading (Service Level 'B')

$$P = (F_x^2 + F_y^2)^{1/2}$$

$$M = (M_x^2 + M_y^2 + M_z^2)^{1/2}$$

Static

$$P = 0$$

$$M = 0$$

$$F_z = 3.7$$

Dynamic

$$P = (2.5^2 + 0.3^2)^{1/2} = 2.52$$

$$M = (1.2^2 + 2.0^2)^{2\ 1/2} = 2.333$$

$$F_z = 1.5$$

Therefore, the following will be used to calculate the largest mechanical load range. Note: the dynamic loads are due to seismic loadings only.

Nozzle Loads (Service Level 'B')

Static

$P = 4.42$ kip

$M = 275.4$ in kip

$F_z = 1.37$ kip

Dynamic

$P = \pm 3.136$ kip

$M = \pm 390.9$ in kip

$F_z = \pm 0.26$ kip

Thermal Sleeve Loads (Service Level 'B')

	$P = \pm 2.52$ kip
Dynamic	$M = \pm 2.333$ in kip
	$F_z = \pm 1.5$ kip
Static	$F_z = 3.7$ kip

4.2.3.2 Mechanical Load Range Calculations. The section properties used are found in Table 3-1 of Section 3. Note, these properties include effects of corrosion. A summary of the calculations is given in Table 4.2.3.2-1.

Section A

Nozzle Loads

$P = 4.42$ kip

$M = 275.4$ in kip

$F_z = 1.37$ kip

$M = 275.4 + 4.42\ (12.83) + 1.37\ (0.56)$

$= 332.9$ in kip

$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{332.9}{51.98} = 6.41$ ksi

$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.37}{19.03} = 0.072$ ksi

$P = \pm\ 3.136$ kip

$M = \pm\ 390.9$ in kip

$F_z = \pm\ 0.26$ kip

$M = 390.9 + 3.136\ (12.83) + 0.26\ (0.56)$

$= 431.3$ in kip

$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{431.3}{51.98} = 8.3$ ksi

$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{0.26}{19.03} = 0.014$ ksi

Thermal Sleeve Loads

$F_z = 3.7$ kip

$M = 3.7\ (2.36) = 8.73$ in kip

$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{8.73}{51.98} = 0.168$ ksi

$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{3.7}{19.03} = 0.195$ ksi

$P = \pm\ 2.52$ kip

$M = \pm\ 2.333$ in kip

$F_z = \pm\ 1.5$ kip

$M = 2.333 + 2.52\ (15.76) + 1.5\ (2.36)$

$= 45.59$ in kip

$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{45.59}{51.98} = 0.877$ ksi

$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.5}{19.03} = 0.079$ ksi

Total Stress

$\sigma_{\phi_{BEND}} = 6{,}578$ psi $= \pm\ 9{,}177$ psi

$\sigma_{\phi_{AX.}} = 267$ psi $= \pm\ 93$ psi

Section B

Nozzle Loads

$P = 4.42$ kip

$M = 275.4$ in kip

$F_z = 1.37$ kip

$$M = 275.4 + 4.42\,(10.22) + 1.37\,(0.56) = 321.34 \text{ in kip}$$

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{321.34}{51.98} = 6.182 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.37}{19.03} = 0.072 \text{ ksi}$$

$P = \pm 3.136$ kip

$M = \pm 390.9$ in kip

$F_z = \pm 0.26$ kip

$$M = 390.9 + 3.136\,(10.22) + 0.26\,(0.56) = 423.1 \text{ in kip}$$

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{423.1}{51.98} = 8.14 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{0.26}{19.03} = 0.014 \text{ ksi}$$

Thermal Sleeve Loads

$F_z = 3.7$ kip

$$M = 3.7\,(2.36) = 8.73 \text{ in kip}$$

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{8.73}{51.98} = 0.168 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{3.7}{19.03} = 0.195 \text{ ksi}$$

$P = \pm 2.52$ kip

$M = \pm 2.333$ in kip

$F_z = \pm 1.5$ kip

$$M = 2.333 + 2.52\,(18.37) + 1.5\,(2.36) = 52.17 \text{ in kip}$$

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{52.17}{51.98} = 1.004 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.5}{19.03} = 0.079 \text{ ksi}$$

Total Stress

$\sigma_{\phi_{BEND}} = 6{,}350$ psi $= \pm 9{,}144$ psi

$\sigma_{\phi_{AX.}} = 267$ psi $= \pm 93$ psi

Section C/D

Nozzle Loads

$P = 4.42$ kip

$M = 275.4$ in kip

$F_z = 1.37$ kip

$M = 275.4 + 4.42\ (7.47) + 1.37\ (0.56)$

$= 309.19$ in kip

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{309.19}{51.98} = 5.952 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.37}{19.03} = 0.072 \text{ ksi}$$

$P = \pm\ 3.136$ kip

$M = \pm\ 390.9$ in kip

$F_z = \pm\ 0.26$ kip

$M = 390.9 + 3.136\ (7.47) + 0.26\ (0.56)$

$= 414.48$ in kip

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{414.48}{51.98} = 7.974 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{0.26}{19.03} = 0.014 \text{ ksi}$$

Thermal Sleeve Loads

$F_z = 3.7$ kip

$M = 3.7\ (2.36) = 8.73$ in kip

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{8.73}{51.98} = 0.168 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{3.7}{19.03} = 0.195 \text{ ksi}$$

$P = \pm\ 2.52$ kip

$M = \pm\ 2.333$ in kip

$F_z = \pm\ 1.5$ kip

$M = 2.333 + 2.52\ (21.12) + 1.5\ (2.36)$

$= 59.10$ in kip

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{59.10}{51.98} = 1.137 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.5}{19.03} = 0.079 \text{ ksi}$$

Total Stress

$\sigma_{\phi_{BEND}} = 6{,}118$ psi $\qquad = \pm\ 9{,}111$ psi

$\sigma_{\phi_{AX.}} = 267$ psi $\qquad = \pm\ 93$ psi

Section E

Nozzle Loads

$P = 4.42$ kip

$M = 275.4$ in kip

$F_z = 1.37$ kip

$$M = 275.4 + 4.42\ (4.72) + 1.37\ (0.56)$$

$$= 297.03 \text{ in kip}$$

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{297.03}{51.98} = 5.715 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.37}{19.03} = 0.072 \text{ ksi}$$

$P = \pm 3.136$ kip

$M = \pm 390.9$ in kip

$F_z = \pm 0.26$ kip

$$M = 390.9 + 3.136\ (4.72) + 0.26\ (0.56)$$

$$= 405.85 \text{ in kip}$$

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{405.85}{51.98} = 7.808 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{0.26}{19.03} = 0.014 \text{ ksi}$$

Thermal Sleeve Loads

$F_z = 3.7$ kip

$$M = 3.7\ (2.36) = 8.73 \text{ in kip}$$

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{8.73}{51.98} = 0.168 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{3.7}{19.03} = 0.195 \text{ ksi}$$

$P = \pm 2.52$ kip

$M = \pm 2.333$ in kip

$F_z = \pm 1.5$ kip

$$M = 2.333 + 2.52\ (23.87) + 1.5\ (2.36)$$

$$= 66.03 \text{ in kip}$$

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{66.03}{51.98} = 1.27 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.5}{19.03} = 0.079 \text{ ksi}$$

Total Stress

$\sigma_{\phi_{BEND}} = 5{,}883$ psi $\qquad = \pm 9{,}078$ psi

$\sigma_{\phi_{AX.}} = 267$ psi $\qquad = \pm 93$ psi

Section F

Nozzle Loads

$P = 4.42$ kip

$M = 275.4$ in kip

$F_z = 1.37$ kip

$M = 275.4 + 4.42\ (1.62)$

$= 282.56$ in kip

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{282.56}{39.09} = 7.23 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.37}{15.89} = 0.087 \text{ ksi}$$

$P = \pm 3.136$ kip

$M = \pm 390.9$ in kip

$F_z = \pm 0.26$ kip

$M = 390.9 + 3.136\ (1.62)$

$= 395.98$ in kip

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{395.98}{39.09} = 10.13 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{0.26}{15.89} = 0.017 \text{ ksi}$$

Thermal Sleeve Loads

$F_z = 3.7$ kip

$M = 3.7\ (1.8) = 6.66$ in kip

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{6.66}{39.09} = 0.171 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{3.7}{15.89} = 0.233 \text{ ksi}$$

$P = \pm 2.52$ kip

$M = \pm 2.333$ in kip

$F_z = \pm 1.5$ kip

$M = 2.333 + 2.52\ (26.97) + 1.5\ (1.8)$

$= 73.0$ in kip

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{73}{39.09} = 1.868 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.5}{15.89} = 0.095 \text{ ksi}$$

Total Stress

$\sigma_{\phi_{BEND}} = 7{,}401$ psi $= \pm 11{,}998$ psi

$\sigma_{\phi_{AX.}} = 320$ psi $= \pm 112$ psi

Section G

Nozzle Loads

$P = 4.42$ kip

$M = 275.4$ in kip

$F_z = 1.37$ kip

$M = 275.4 + 4.42\ (4.72) + 1.37\ (1.8)$

$= 298.73$ in kip

$$\sigma_{\phi_{BEND}} = (0.381) = \frac{M}{Z} = (0.381)\ \frac{298.73}{22.32} = 5.1 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{1.37}{10.46} = 0.05 \text{ ksi}$$

$P = \pm\ 3.136$ kip

$M = \pm\ 390.9$ in kip

$F_z = \pm\ 0.26$ kip

$M = 390.9 + 3.136\ (4.72) + 0.26\ (1.8)$

$= 406.17$ in kip

$$\sigma_{\phi_{BEND}} = 0.381\ \frac{M}{Z} = (0.381)\ \frac{406.17}{22.32} = 6.934 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{0.26}{10.46} = 0.01 \text{ ksi}$$

Thermal Sleeve Loads

$F_z = 3.7$ kip

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{3.7}{10.46} = 0.354 \text{ ksi}$$

$P = \pm\ 2.52$ kip

$M = \pm\ 2.333$ in kip

$F_z = \pm\ 1.5$ kip

$M = 2.333 + 2.52\ (23.87)$

$= 62.49$ in kip

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{62.49}{22.32} = 2.8 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.5}{10.46} = 0.144 \text{ ksi}$$

Total Stress

$\sigma_{\phi_{BEND}} = 5{,}100$ psi $= \pm\ 9{,}734$ psi

$\sigma_{\phi_{AX.}} = 404$ psi $= \pm\ 154$ psi

Section H

Nozzle Loads

$P = 4.42$ kip

$M = 275.4$ in kip

$F_z = 1.37$ kip

$M = 275.4 + 4.42\ (8.47) + 1.37\ (1.8)$

$= 315.3$ in kip

$\sigma_{\phi_{BEND}} = (0.381) = \frac{M}{Z} = (0.381)\ \frac{315.3}{22.32} = 5.383$ ksi

$\sigma_{\phi_{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{1.37}{10.46} = 0.05$ ksi

$P = \pm\ 3.136$ kip

$M = \pm\ 390.9$ in kip

$F_z = \pm\ 0.26$ kip

$M = 390.9 + 3.136\ (8.47) + 0.26\ (1.8)$

$= 417.93$ in kip

$\sigma_{\phi_{BEND}} = 0.381\ \frac{M}{Z} = (0.381)\ \frac{417.93}{22.32} = 7.134$ ksi

$\sigma_{\phi_{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{0.26}{10.46} = 0.01$ ksi

Thermal Sleeve Loads

$F_z = 3.7$ kip

$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{3.7}{10.46} = 0.354$ ksi

$P = \pm\ 2.52$ kip

$M = \pm\ 2.333$ in kip

$F_z = \pm\ 1.5$ kip

$M = 2.333 + 2.52\ (20.12)$

$= 53.04$ in kip

$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{53.04}{22.32} = 2.377$ ksi

$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.5}{10.46} = 1.44$ ksi

Total Stress

$\sigma_{\phi_{BEND}} = 5{,}383$ psi $= \pm\ 9{,}511$ psi

$\sigma_{\phi_{AX.}} = 404$ psi $= \pm\ 154$ psi

Section I

Nozzle Loads

$P = 4.42$ kip

$M = 275.4$ in kip

$F_z = 1.37$ kip

$M = 275.4 + 4.42\ (8.47) + 1.37\ (1.8)$

$= 315.3$ in kip

$$\sigma_{\phi_{BEND}} = (0.381) = \frac{M}{Z} = (0.381)\ \frac{315.3}{29.07} = 4.133 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{1.37}{13.78} = 0.038 \text{ ksi}$$

$P = \pm\ 3.136$ kip

$M = \pm\ 390.9$ in kip

$F_z = \pm\ 0.26$ kip

$M = 390.9 + 3.136\ (8.47) + 0.26\ (1.8)$

$= 417.93$ in kip

$$\sigma_{\phi_{BEND}} = 0.381\ \frac{M}{Z} = (0.381)\ \frac{417.93}{29.07} = 5.478 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{0.26}{13.78} = 0.008 \text{ ksi}$$

Thermal Sleeve Loads

$F_z = 3.7$ kip

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{3.7}{13.78} = 0.269 \text{ ksi}$$

$P = \pm\ 2.52$ kip

$M = \pm\ 2.333$ in kip

$F_z = \pm\ 1.5$ kip

$M = 2.333 + 2.52\ (20.12)$

$= 53.04$ in kip

$$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{53.04}{29.07} = 1.83 \text{ ksi}$$

$$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.5}{13.78} = 0.109 \text{ ksi}$$

Total Stress

$\sigma_{\phi_{BEND}} = 4{,}133$ psi $= \pm\ 7{,}308$ psi

$\sigma_{\phi_{AX.}} = 307$ psi $= \pm\ 117$ psi

Section J

Nozzle Loads

$P = 4.42$ kip

$M = 275.4$ in kip

$F_z = 1.37$ kip

$M = 275.4 + 4.42\ (9.26) + 1.37\ (1.8)$

$= 318.8$ in kip

$\sigma_{\phi_{BEND}} = (0.381) = \frac{M}{Z} = (0.381)\ \frac{318.8}{29.07} = 4.179$ ksi

$\sigma_{\phi_{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{1.37}{13.78} = 0.038$ ksi

$P = \pm\ 3.136$ kip

$M = \pm\ 390.9$ in kip

$F_z = \pm\ 0.26$ kip

$M = 390.9 + 3.136\ (9.26) + 0.26\ (1.8)$

$= 420.4$ in kip

$\sigma_{\phi_{BEND}} = 0.381\ \frac{M}{Z} = (0.381)\ \frac{420.4}{29.07} = 5.51$ ksi

$\sigma_{\phi_{AX.}} = 0.381\ \frac{F_z}{A} = (0.381)\ \frac{0.26}{13.78} = 0.008$ ksi

Thermal Sleeve Loads

$F_z = 3.7$ kip

$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{3.7}{13.78} = 0.269$ ksi

$P = \pm\ 2.52$ kip

$M = \pm\ 2.333$ in kip

$F_z = \pm\ 1.5$ kip

$M = 2.333 + 2.52\ (19.33)$

$= 51.05$ in kip

$\sigma_{\phi_{BEND}} = \frac{M}{Z} = \frac{51.05}{29.07} = 1.756$ ksi

$\sigma_{\phi_{AX.}} = \frac{F_z}{A} = \frac{1.5}{13.78} = 0.109$ ksi

Total Stress

$\sigma_{\phi_{BEND}} = 4{,}179$ psi $= \pm\ 7{,}266$ psi

$\sigma_{\phi_{AX.}} = 307$ psi $= \pm\ 117$ psi

TABLE 4.2.3.2-1 MAXIMUM MECHANICAL LOAD STRESS INTENSITY (Service Level 'B')

Section	Static Stress	Dynamic Stress*
A	6,845	± 9,270
B	6,617	± 9,237
C	6,385	± 9,204
D	6,385	± 9,204
E	6,150	± 9,171
F	7,721	± 12,110
G	5,504	± 9,888
H	5,787	± 9,665
I	4,440	± 7,425
J	4,486	± 7383

(All stress in psi)

* Dynamic stresses are due to seismic only.

4.2.4 <u>Pressure Stress Analysis.</u> The pressure stresses were obtained using the finite element computer program ANSYS. The same finite element model used for the thermal stress analysis (described in Paragraph 4.2.2 and Figure 4.1.1-1) was also used for the pressure stress analysis. The modeling of the portion of the vessel wall as a disc is a nonconservative assumption. It is recognized that the pressure stresses in the vessel wall regions obtained from using this model are not strictly valid. However, stresses in the safe end-thermal sleeve regions are valid since the effect of this modeling in these regions is insignificant. The applied boundary condition at the isolated surfaces of the safe end and thermal sleeve was the equivalent meridional stress caused by the pressure. The vessel boundary condition was the average of the hoop and meridional stresses.

4.2.4.1 <u>Pressure Stress Analysis Results.</u> The pressure stresses were evaluated for the specified pressures of 1,111 psig nozzle pressure and 1,000 psig vessel pressure. The pressure membrane plus bending stresses are tabulated in Table 4.2-9. The pressure membrane plus bending plus peak stresses are tabulated in Table 4.2-18. Figures 4.2.4-1 and 4.2.4-2 show an isostress plot and a deflection plot of the pressure case.

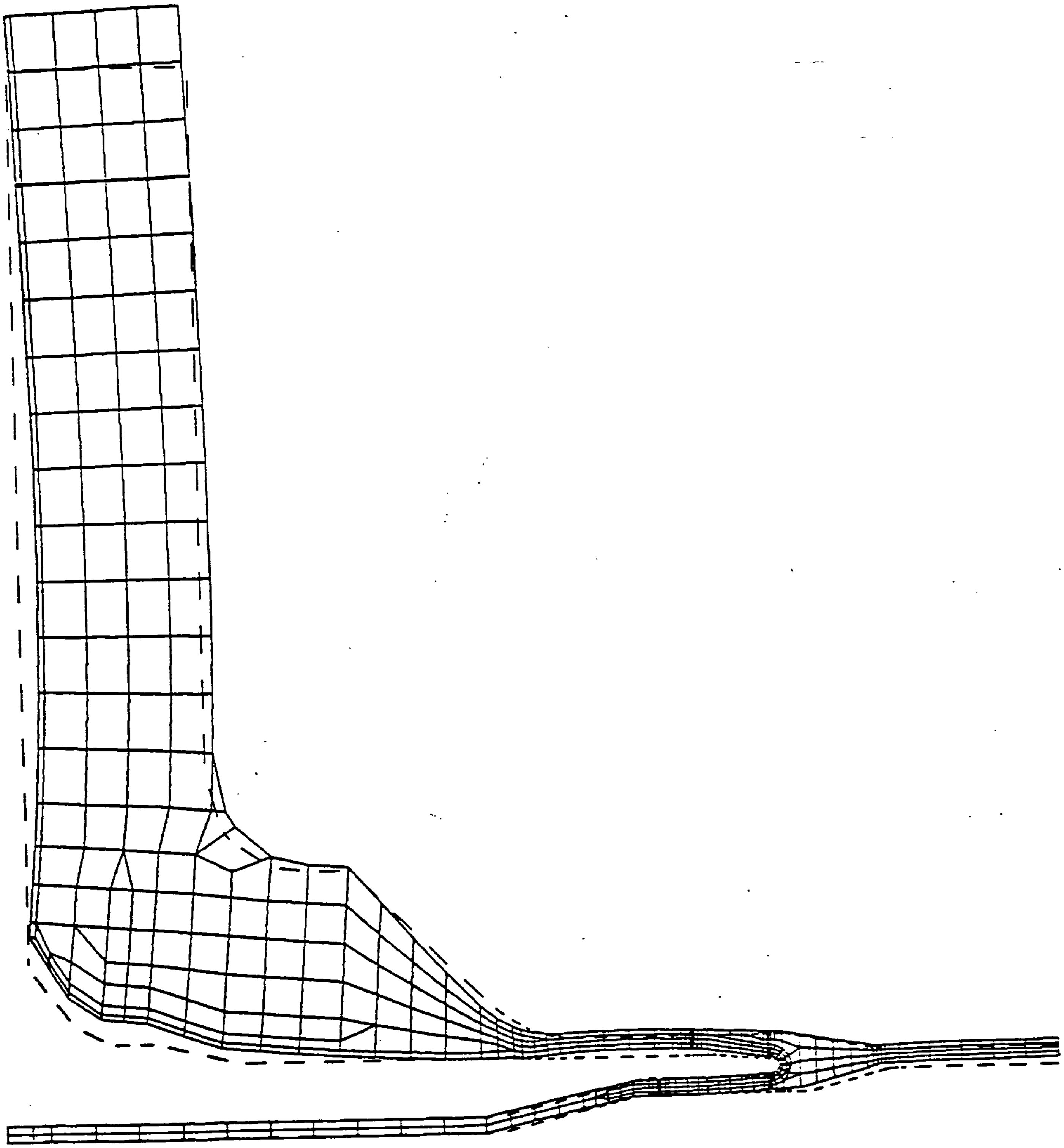


FIGURE 4.2.4-1 MONTICELLO FEEDWATER NOZZLE STRESS ANALYSIS - DISPLACEMENT PLOT (PRESSURE RUN)

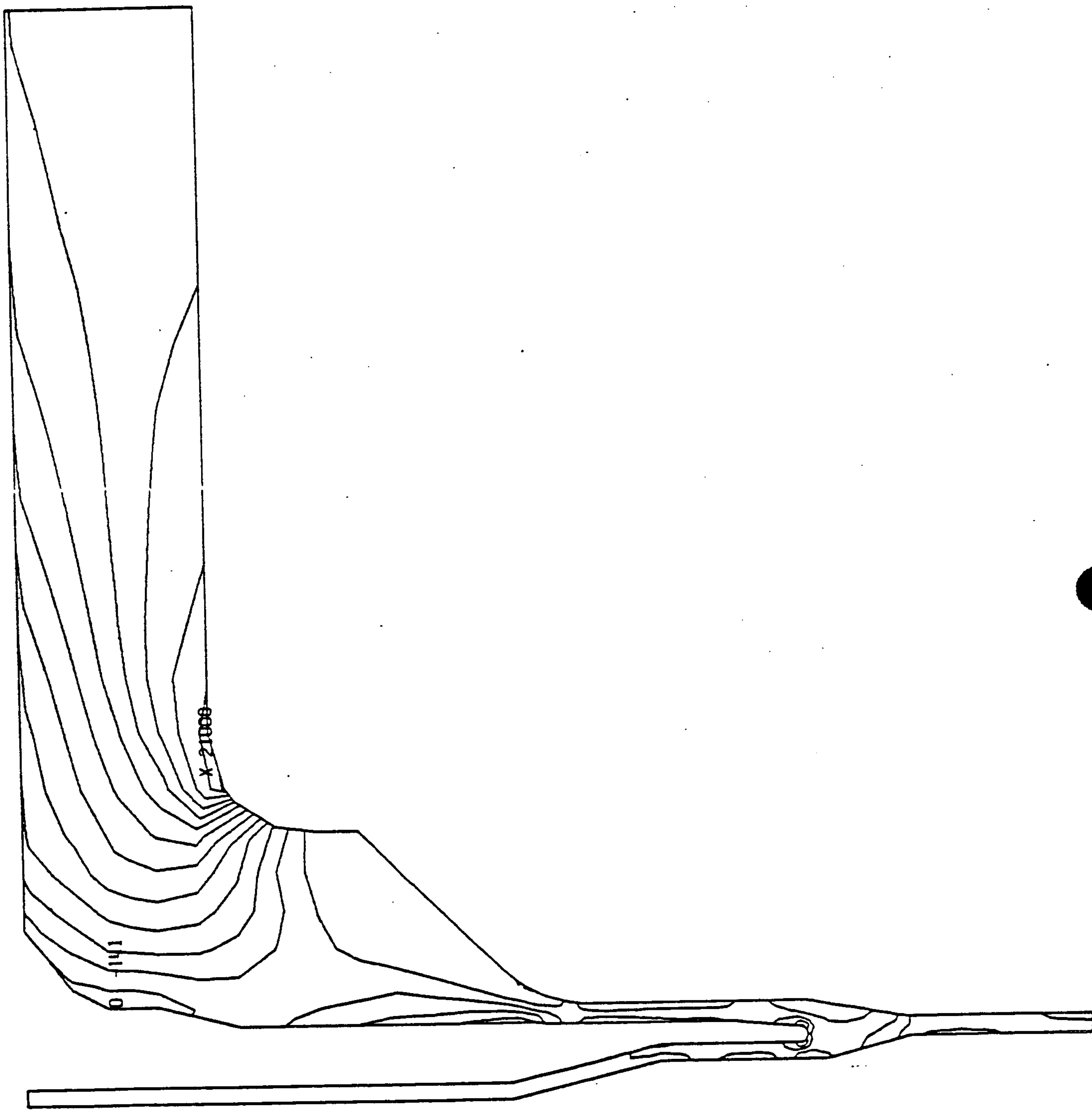


FIGURE 4.2.4-2 MONTICELLO FEEDWATER NOZZLE STRESS ANALYSIS - STRESS PLOT (PRESSURE RUN)

4.2.5 Total Primary Plus Secondary Stress Ranges. This section of the report calculates the P+Q stress intensity ranges at the previously selected locations in order to validate the subsequent fatigue analysis. These stress ranges are calculated as the sum of three independent ranges; one for thermal stresses, a second for the maximum safe end and thermal sleeve load stresses, and a third for the pressure stresses.

4.2.5.1 Thermal Stress Ranges. The maximum thermal membrane plus bending stress ranges can be found by inspection using Tables 4.2-1 through 4.2-8. Table 4.2.5-1 will be used to identify the transient times used in the thermal analysis.

TABLE 4.2.5-1 TRANSIENTS USED IN THERMAL STRESS EVALUATION

1. Cool Down (t = 6.0 sec)
2. Cool Down (t = 15.0 sec)
3. Cool Down (t = 60.0 sec)
4. Cool Down (t = steady state)
5. Heat Up (t = 2.0 sec)
6. Heat Up (t = 3.0 sec)
7. Heat Up (t = 12.0 sec)
8. Normal Operation
9. Stress Free

The maximum thermal membrane plus bending stress ranges are found to be as follows:

Location	Maximum Stress Range (psi)	Cases
A	4,709	1-7
B	4,907	1-7
C	11,917	1-6
D	12,188	1-6
E	18,275	2-9
F	28,777	1-7
G	34,852	2-9
H	38,999	1-9
I	43,017	1-9
J	38,310	2-9

4.2.5.2 <u>Nozzle End and Thermal Sleeve Load Stress Ranges.</u> The maximum nozzle end and thermal sleeve load stress ranges are found using Table 4.2.3.2-1. The maximum stress ranges are as follows:

Location	Maximum P+Q (ksi)
A	18.54
B	18.48
C	18.41
D	18.41
E	18.35
F	24.22
G	19.78
H	19.33
I	14.85
J	14.77

4.2.5.3 <u>Pressure Stress Ranges.</u> The pressure membrane plus bending stress ranges are found using Table 4.2-9. The P+Q pressure stress intensities are found to be as follows:

Location	S_n (psi)
A	5,963
B	9,437
C	8,941
D	8,873
E	6,524
F	8,678
G	7,654
H	4,567
I	4,670
J	6,229

4.2.5.4 <u>Total P+Q Range.</u> The total primary plus secondary stress range for the selected locations is as follows:

Location	P+Q (ksi)
A	29.22
B	32.83
C	39.27
D	39.48
E	43.15
F	61.68
G	62.29
H	62.90
I	62.54
J	59.31

The limit for the primary plus secondary stress intensity is 3 S_m. At 550°F, carbon steel (SA-350 LF2) has a S_m of 18.6 ksi, and stainless steel (SA-351 CF3) has a S_m of 16.0 ksi. In calculating 3 S_m, it is seen that Sections F through J are in excess of their limits, therefore, the simplified elastic-plastic method will be used. For the simplified elastic-plastic fatigue analysis to be valid, the primary plus secondary minus thermal bending must be less than 3 S_m. So for Sections F through J, P+Q excluding thermal bending will be calculated.

The maximum thermal membrane stress ranges are found to be as follows: [Calculations included in DRF (Reference 6.5)]

Location	Thermal Membrane Range (psi)	Cases
F	3,705	2-7
G	17,979	3-9
H	16,964	1-9
I	13,669	8-9
J	3,117	8-9

Therefore, the total P+Q stress intensity ranges excluding thermal bending are found to be:

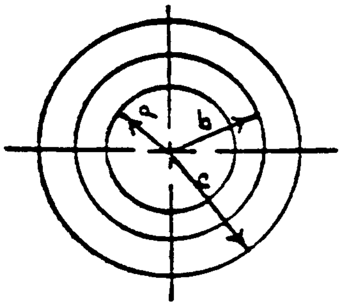
Location	P+Q (ksi)	3 S_m (ksi)
F	36.61	55.8
G	45.42	55.8
H	40.87	55.8
I	33.19	48.0
J	24.12	48.0

4.2.6 Interference Fit Stresses. Since both male and female members are stainless steel, both member's respective moduli are equal

From Shigley - Page 78 (Reference 6.14)

$$P = \frac{E\delta}{b} \quad \frac{(c^2 - b^2)(b^2 - a^2)}{2b^2(c^2 - a^2)}$$

Now the dimensions (from Reference 6.13, 6.9, and 6.8)



a = 2.71 in

b = 3.19 in

c = 3.69 in

max δ = 0.0065 in
or
0.013 in dia.

Also - yield highest stresses at room temperature

$$E = 28.3 \times 10^6 \text{ psi}$$

$$P = \frac{(28.3 \times 10^6)(0.0065)}{3.19} \quad \frac{(3.69^2 - 3.19^2)(3.19^2 - 2.71^2)}{2(3.19)^2 \ (3.69^2 - 2.71^2)} = 4{,}401. \text{ psi}$$

Hoop stresses for the inner and outer members are as follows:

$$\sigma_{\theta} \text{ inner} = -P \frac{b^2 + a^2}{b^2 - a^2} = -27{,}228 \text{ psi}$$

$$\sigma_{\theta} \text{ outer} = P \frac{c^2 + b^2}{c^2 - b^2} = 30{,}438 \text{ psi}$$

The total hoop stresses at this location includes a pressure effect.

$$\sigma_{\theta} = \frac{PD}{2t} = \frac{111(6.16)}{2(0.5)} = 684 \text{ psi}$$

By inspection, the total P+Q stresses for this location are less than the allowed 3 S_m limit (3 S_m = 48 ksi). This section will not be examined again.

TABLE 4.2-1 THERMAL MEMBRANE PLUS BENDING STRESSES (CASE 1)

Cool Down (t = 6.0 seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	2,679	2,390	-	-2,442	-2,165	-
B	2,892	2,972	-	-2,620	-2,659	-
C	2,723	2,662	-	-2,413	-3,880	-
D	2,748	2,596	-	-2,437	-3,953	-
E	9,820	169	-	-9,251	-9,885	-
F	28,589	21,490	-	-26,331	-20,696	-
G	16,087	29,153	-	-15,027	-7,305	-
H	27,845	38,999	-	-26,414	-5,073	-
I	28,682	15,876	-	-23,569	-43,017	-
J	26,741	31,274	-	-22,590	-34,654	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.2-2 THERMAL MEMBRANE PLUS BENDING STRESSES (CASE 2)

Cool Down (t = 15.0 seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	2,532	2,223	-	-2,345	-1,933	-
B	2,381	2,615	-	-2,180	-2,150	-
C	1,226	1,370	-	-1,034	-3,756	-
D	1,243	1,230	-	-1,050	-3,894	-
E	16,142	-3,012	-	-15,293	-18,275	-
F	28,685	19,599	-	-26,724	-17,769	-
G	3,827	34,852	-	-4,068	7,377	-
H	28,805	33,739	-	-27,954	-10,155	-
I	29,154	20,294	-	-25,852	-39,015	-
J	29,003	34,673	-	-26,491	-38,310	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.2-3 THERMAL MEMBRANE PLUS BENDING STRESSES (CASE 3)

Cool Down (t = 60. seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	328	863	-	-291	-8	-
B	554	1,109	-	-517	103	-
C	-3,992	-1,074	-	-3,866	202	-
D	-4,168	-1,298	-	4,036	93	-
E	9,787	-8,278	-	-9,304	-16,283	-
F	16,829	8,280	-	-15,898	-7,339	-
G	-4,453	26,808	-	3,696	9,150	-
H	28,236	29,932	-	-27,688	-12,507	-
I	28,528	21,439	-	-26,195	-36,052	-
J	30,698	35,913	-	-29,186	-37,833	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.2-4 THERMAL MEMBRANE PLUS BENDING STRESSES (CASE 4)

Cool Down (t = steady state) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	-1,083	75	-	1,050	655	-
B	-1,084	766	-	1,054	1,308	-
C	-8,213	-3,595	-	7,884	1,686	-
D	-8,452	-3,914	-	8,114	1,579	-
E	6,431	-8,180	-	-6,247	-8,762	-
F	12,842	1,706	-	-12,215	-6,227	-
G	186	17,261	-	-545	99	-
H	27,722	30,407	-	-27,204	-11,813	-
I	28,097	21,945	-	-25,794	-35,367	-
J	30,926	36,270	-	-29,414	-37,645	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.2-5 THERMAL MEMBRANE PLUS BENDING STRESSES (CASE 5)

Heat Up (t = 2.0 seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	-1,485	-235	-	-1,393	-1,009	-
B	1,521	204	-	1,521	1,791	-
C	-8,885	-4,262	-	8,458	2,412	-
D	-9,129	-4,574	-	8,694	2,314	-
E	5,083	-8,486	-	-5,005	-7,446	-
F	5,694	-4,237	-	-5,899	-835	-
G	-5,412	10,737	-	4,408	3,684	-
H	22,221	25,867	-	-22,841	-7,180	-
I	22,531	14,531	-	-21,391	-30,069	-
J	24,286	28,860	-	-24,354	-30,295	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.2-6 THERMAL MEMBRANE PLUS BENDING STRESSES (CASE 6)

Heat Up (t = 3.0 seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	-1,828	-561	-	1,712	-1,308	-
B	-1,982	-156	-	1,854	2,126	-
C	-9,194	-4,564	-	8,748	2,848	-
D	-9,440	-4,869	-	8,984	2,757	-
E	4,102	-8,505	-	-4,073	-6,434	-
F	2,116	-6,930	-	-2,496	1,856	-
G	-7,342	7,633	-	6,342	4,635	-
H	20,041	24,289	-	-20,825	-4,890	-
I	20,459	11,332	-	-19,388	-27,807	-
J	21,565	26,078	-	-21,894	-26,953	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.2-7 THERMAL MEMBRANE PLUS BENDING STRESSES (CASE 7)

Heat Up (t = 12.0 seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	-2,030	-738	-	1,927	1,439	-
B	-2,015	-244	-	1,906	2,155	-
C	-8,781	-4,249	-	8,375	3,056	-
D	-9,024	-4,522	-	8,608	2,993	-
E	1,166	-7,155	-	-1,263	-2,599	-
F	167	-7,287	-	-415	1,709	-
G	-2,698	4,763	-	2,319	-1,662	-
H	19,881	26,925	-	-20,309	-2,510	-
I	20,516	9,822	-	-18,572	-28,958	-
J	-19,335	24,115	-	-19,124	-24,777	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.2-8 THERMAL MEMBRANE PLUS BENDING STRESSES (CASE 8)

(Normal Operation) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	-3	-357	-	3	-302	-
B	-610	209	-	593	549	-
C	-3,615	-1,675	-	3,470	674	-
D	-3,711	-1,812	-	3,563	619	-
E	3,456	-3,492	-	-3,349	-4,116	-
F	4,754	285	-	-4,521	-2,520	-
G	-432	7,902	-	218	289	-
H	12,072	25,112	-	-13,090	5,539	-
I	12,769	-1,322	-	-10,602	-26,016	-
J	7,786	10,666	-	-7,411	-16,899	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.2-9 THERMAL MEMBRANE PLUS BENDING STRESSES

Pressure Case All stresses in psi

Nozzle Pressure = 1,111 psi
Vessel Pressure = 1,000 psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	1,127	4,963	-1,000	3,496	5,194	-
B	589	8,437	-1,000	4,276	8,618	-
C	1,037	7,941	-1,000	3,837	7,931	-
D	1,086	7,873	-1,000	3,790	7,846	-
E	5,524	5,476	-1,000	-1,961	2,522	-
F	5,432	7,567	-1,111	4,393	6,492	-
G	-1,430	3,615	-1,111	6,654	5,531	-1,000
H	3,189	-1,378	-1,111	2,294	-1,557	-1,000
I	3,289	-1,381	-1,111	2,194	-1,612	-1,000
J	4,962	-1,267	-1,111	658	-2,457	-1,000

Sections Illustrated in Figure 4.2.1-1.

4.3 Fatigue Analysis. This section provides all the detailed fatigue analysis required to show an acceptable design for the operating transients imposed on the nozzle and safe end assembly. (Service Level 'B' Events)

4.3.1 Stress Concentration Factors

Section A

The geometry of the outside surface of Section A is illustrated in Figure 4.3-1. To calculate the stress concentration factor, Reference 6.6 will be used.

NOTE: $$\frac{r}{t} = \frac{3.88}{.65} = 5.97$$

Using Paragraph A.7.2.6 (Reference 6.6),

$$D = 2T = 12.12 \text{ in}$$

$$d = 2t = 1.3 \text{ in}$$

K_o is found from Figure A.7-1, since the scale stops at r/t = 3.6, that value is assumed.

$$K_o = 1.24$$

Using Paragraph A.7.2.4, for r < h

$$\frac{K' - 1}{K_o - 1} = 1 - \left(\frac{\beta}{90}\right)^{1 + 2.4\sqrt{r/h}}$$

Solving for K', obtain

$$K' = 1 + 0.24 \quad 1 - \left(\left(\frac{45}{90}\right)^{1 + 2.4\sqrt{\frac{3.88}{5.41}}}\right)$$

$$K_t = 1.21$$

Section F

The geometry of Section F is illustrated in Figure 4.? To calculate the stress concentration factor, Reference 6.6 will be used. A concentration factor for both the inner and outer surface will be calculated, however, only the largest will be used.

Assume $r \cong 0$, hence $K_o = 4.0$.

Then using Paragraph A.7.2.4 (Reference 6),

$$\frac{(K' - 1)}{(K_o - 1)} = 1 - \frac{\beta}{90}$$

Solving for K', using $\beta_{inner} = 72.3°$ and $\beta_{outer} = 75.74°$

$K'_{inner} = 1.59$

$K'_{outer} = 1.48$

$\therefore\ K_t = 1.59$

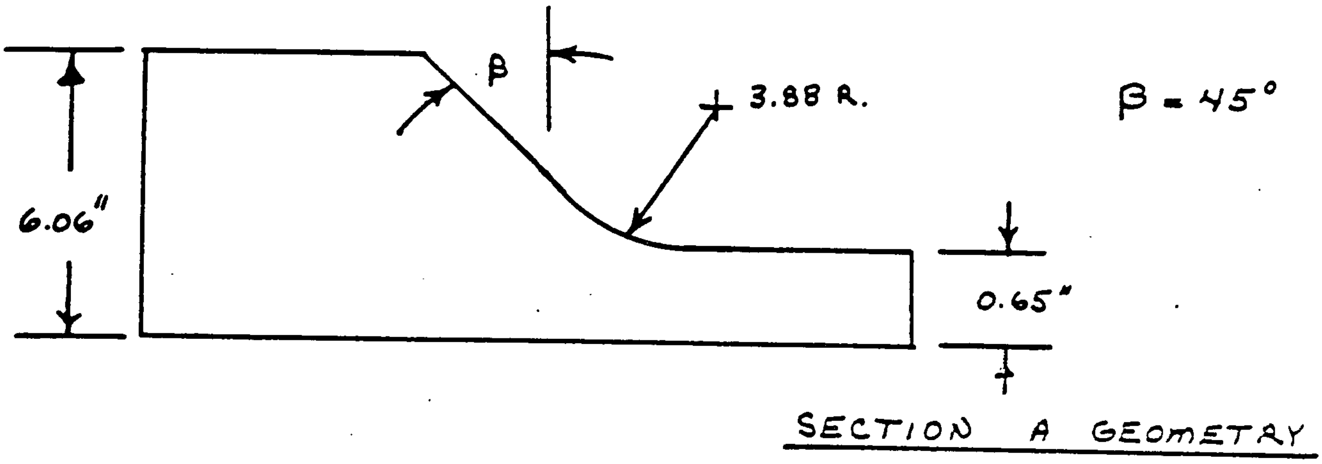


FIGURE 4.3-1

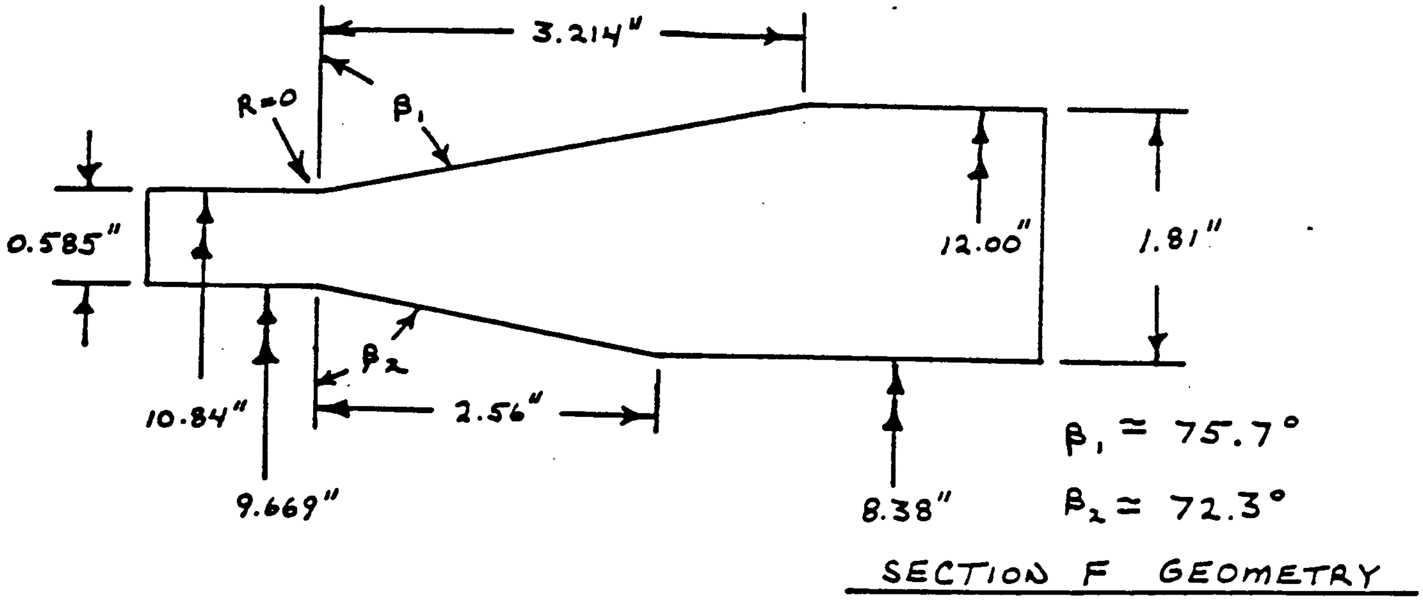


FIGURE 4.3-2

Sections E and G

The geometry of Sections E and G are illustrated in Figure 4.3-3. Also in Figure 4.3-3, is the idealized geometry used to obtain the factor. To obtain the stress concentration factor, Reference 6.6 will be used. Using Figure A.7-1 of Reference 6.6, obtain

For Section E; $r/t = 0.30$ $K_t = 2.15$

and for Section G; $r/t = 0.50$ $K_t = 1.80$

Section J

The geometry of Section J is illustrated in Figure 4.3-4. ANSYS, which was used to obtain the stress levels of the nozzle and safe end accounts for global discontinuities only. Therefore, only the local discontinuity stress concentration factor must be found. Conservatively, use Paragraph A.7.2.4 (Reference 6.6).

Assume $r \cong 0$, and hence $K_o = 4.0$.

Then using Paragraph A.7.2.4 (Reference 6.6), obtain

$$\frac{(K' - 1)}{(K_o - 1)} = 1 - \frac{\beta}{90}$$

Solving for K', using $\beta = 76.44°$

$$K' = 1 + 3 \left(1 - \frac{76.44}{90}\right)$$

$$\therefore \; K_t = 1.452$$

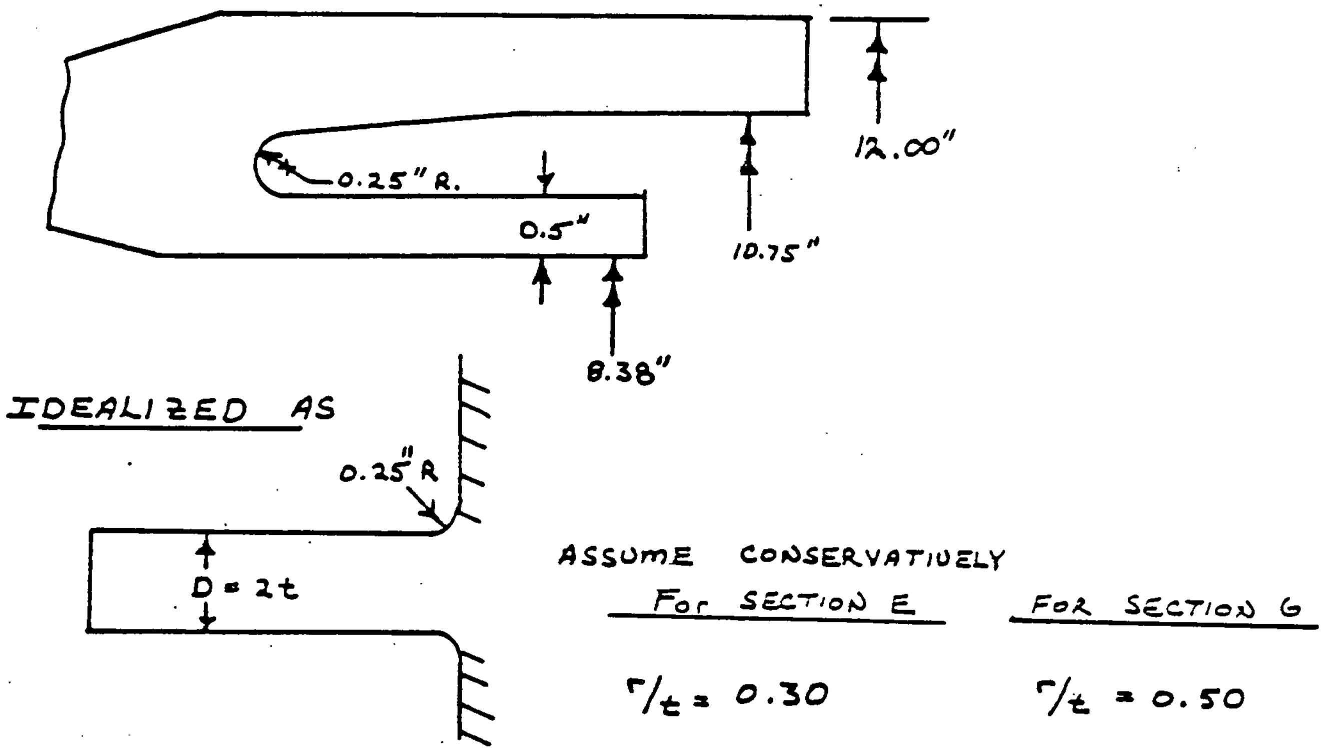


FIGURE 4.3-3 SECTION E AND G GEOMETRY

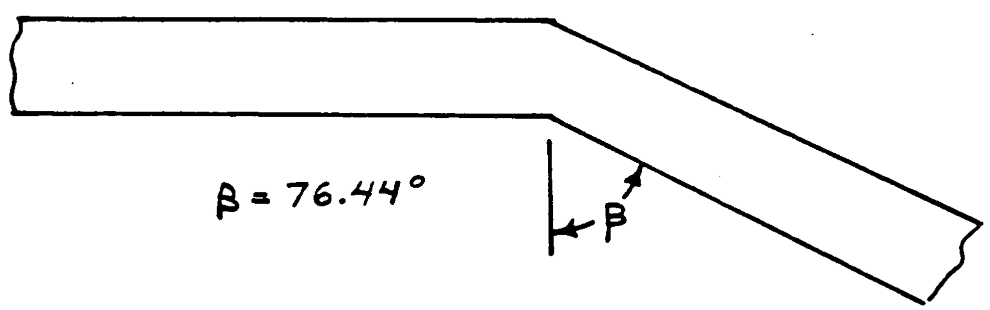


FIGURE 4.3-4 SECTION J GEOMETRY

Sections B, C, D, H, and I

All of these sections are at locations of welds. A conservative stress concentration factor will be put on these locations. For pipe joined by butt welds, the thermal K_t is 1.8 (Reference 6.2). This will be assumed here.

$$K_t = 1.8$$

4.3.2 Alternating Stress Range. To calculate the alternating stress range, the following equation is used.

$$S_{alt} = 1/2\ K_e(K_t S_N + F_1)$$

where:

K_t = stress concentration factor

K_e = simplified elastic-plastic factor

S_N = P+Q stress intensity

F_1 = peak stress identified by 'NONO' program

The peak stress identified by the 'NONO' program is found using Tables 4.3-3 through 4.3-11. These tables contain the total surface stresses at each section. A conservative method of obtaining these peak stresses is to find the largest stress intensity range for the surface stresses and subtracting the P+Q stress intensity found earlier in Paragraph 4.2.5. This was followed and the results are given in Table 4.3-1. Also in Table 4.3-1 is the stress intensity range for the mechanical load case which does not include seismic loads. These are needed to calculate the P+Q range excluding seismic, hence the alternating stress range excluding seismic is given.

4.3.2 (Continued)

The total alternating stress range is calculated for both seismic loading included and seismic loading not included. The simplified elastic-plastic factor is defined by the following (Reference 6.2).

1.0 for $S_N < 3S_m$

$$1 + \frac{(1 - n)}{n(m - 1)} \left(\frac{S_N}{3S_m} - 1 \right) \quad \text{for } 3S_m < S_N < m3S_m$$

$1/n$ for $m3S_m < S_N$.

where:

for carbon steel

$n = 0.2$
$m = 3$

for stainless steel

$n = 0.3$
$m = 1.7$

S_N = P+Q stress intensity range

The results are tabulated in Table 4.3-2.

TABLE 4.3-1 CALCULATION OF PEAK STRESS

All stresses in ksi

Thermal 'Skin' Stresses Included

Location	Mechanical Range (Seismic)	Mechanical Range (No Seismic)	Thermal Range	Cases*	Pressure Range	Maximum Surface Stress Range	S_N** P+Q	(F_1) Peak Stress
A	18.54	6.85	5.93	1-7	6.22	30.69	29.22	1.47
B	18.48	6.62	6.78	1-6	9.64	34.90	32.83	2.07
C	18.41	6.39	14.69	1-6	8.96	42.06	39.27	2.79
D	18.41	6.39	14.98	1-6	8.89	43.28	39.48	2.80
E	18.35	6.15	26.20	2-9	9.53	54.08	43.15	10.93
F	24.22	7.73	40.55	1-6	8.83	73.6	61.68	11.92
G	19.78	5.51	38.81	2-9	10.15	68.74	62.29	6.45
H	19.33	5.79	44.73	1-9	4.76	68.82	62.90	5.92
I	14.85	4.44	50.94	1-9	4.91	70.7	62.54	8.16
J	14.77	4.49	55.52	1-9	7.79	78.08	59.31	18.77

* Cases shown in Table 4.2.5-1

** From Section 4.2.5.4

TABLE 4.3-2 CALCULATION OF ALTERNATING STRESS

All stresses in ksi

Location	S_{N_1} *	S_{N_2} +*	K_t	$\left(F_1\right)$ Peak Stress	K_{e_1} *	K_{e_2} *	S_{alt_1} *	S_{alt_2} *
A	29.22	17.53	1.21	1.47	1.0	1.0	18.42	11.34
B	32.83	20.97	1.8	2.07	1.0	1.0	30.6	19.91
C	39.27	27.25	1.8	2.79	1.0	1.0	36.8	26.0
D	39.48	27.46	1.8	2.80	1.0	1.0	37.0	26.2
E	43.15	30.95	2.15	10.93	1.0	1.0	51.9	38.8
F	61.68	45.19	1.59	11.93	1.21	1.0	66.6	41.9
G	62.29	48.02	1.8	6.45	1.233	1.0	73.1	46.5
H	62.90	49.36	1.8	5.92	1.255	1.0	74.8	47.4
I	62.54	52.13	1.8	8.16	2.01	1.287	121.4	65.7
J	59.31	49.03	1.45	18.77	1.786	1.072	93.6	48.2

* Subscript 1 for seismic; Subscript 2 for no seismic loads

+ S_{N_2} found using Section 4.2.5 and Table 4.2.3.2-1

TABLE 4.3-3 THERMAL 'SKIN' STRESSES ($P + Q + F_1$) (CASE 1)

Cool Down (t = 6.0 seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	3,623	3,419	-	-1,873	-1,494	-
B	4,183	4,353	-	-1,797	-1,792	-
C	4,340	4,422	-	-1,292	-2,749	-
D	4,368	4,357	-	-1,317	-2,823	-
E	16,358	3,038	-	-7,253	-8,440	-
F	38,712	29,769	-	-21,225	-15,334	-
G	23,724	37,262	-	-10,544	-1,992	-
H	33,822	44,723	-	-27,107	-4,255	-
I	50,935	38,423	-	-4,123	-24,635	-
J	50,037	55,518	-	-5,889	-17,421	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.3-4 THERMAL 'SKIN' STRESSES (P + Q + F_1) (CASE 2)

Cool Down (t = 15.0 seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	3,113	2,877	-	-1,992	-1,470	-
B	3,206	3,518	-	-1,602	-1,531	-
C	2,230	2,558	-	-128	-2,882	-
D	2,250	2,418	-	-140	-3,019	-
E	26,195	5	-	-12,272	-16,508	-
F	36,613	25,636	-	-23,420	-13,914	-
G	7,629	38,809	-	-75	9,598	-
H	29,686	35,301	-	-33,577	-13,094	-
I	39,914	31,376	-	-17,613	-31,359	-
J	40,400	46,428	-	-19,565	-31,097	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.3-5 THERMAL 'SKIN' STRESSES (P + Q + F_1) (CASE 3)

Cool Down (t = 60. seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	428	983	-	-189	75	-
B	702	1,269	-	-419	219	-
C	-4,004	-867	-	4,317	467	-
D	-4,189	-1,119	-	4,505	360	-
E	17,328	-6,934	-	-6,859	-15,349	-
F	20,038	10,184	-	-15,449	-6,371	-
G	-2,865	28,192	-	7,709	9,610	-
H	26,786	29,469	-	-35,539	-17,295	-
I	33,583	26,665	-	-23,875	-34,231	-
J	35,206	40,230	-	-29,417	-37,795	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.3-6 THERMAL 'SKIN' STRESSES ($P + Q + F_1$) (CASE 4)

Cool Down (t = steady state) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	-1,123	42	-	1,160	649	-
B	-1,158	722	-	1,112	1,321	-
C	-8,705	-3,860	-	8,344	1,738	-
D	-8,961	-4,203	-	8,593	1,631	-
E	11,513	-8,565	-	-5,060	-9,135	-
F	14,726	2,289	-	-12,418	-6,132	-
G	1,099	18,047	-	1,083	-166	-
H	26,237	29,924	-	-35,042	-16,606	-
I	33,098	27,126	-	-23,496	-33,584	-
J	35,424	40,531	-	-29,711	-37,674	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.3-7 THERMAL 'SKIN' STRESSES ($P + Q + F_1$) (CASE 5)

Heat Up (t = 2.0 seconds) All str ~s in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	-1,875	-635	-	1,352	840	-
B	-2,200	-356	-	1,341	1,560	-
C	-10,008	-5,183	-	8,597	2,139	-
D	-10,271	-5,520	-	8,851	2,041	-
E	8,835	-9,759	-	-4,209	-8,158	-
F	2,762	-7,988	-	-8,384	-3,018	-
G	-8,872	7,052	-	3,722	816	-
H	14,115	20,018	-	-34,578	-15,131	-
I	20,488	11,739	-	-23,383	-32,975	-
J	17,903	22,761	-	-30,218	-35,591	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.3-8 THERMAL 'SKIN' STRESSES ($P + Q + F_1$) (CASE 6)

Heat Up (t = 3.0 seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	-2,278	-1,029	-	1,591	1,048	-
B	-2,592	-763	-	1,599	1,813	-
C	-10,347	-5,531	-	8,800	2,485	-
D	-10,611	-5,861	-	9,056	2,395	-
E	7,369	-9,907	-	-3,462	-7,280	-
F	-1,128	-10,780	-	-5,368	-752	-
G	-10,334	4,345	-	5,903	1,739	-
H	11,751	18,369	-	-33,126	-13,254	-
I	18,842	8,825	-	-21,948	-31,365	-
J	14,040	19,115	-	-29,368	-33,807	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.3-9 THERMAL 'SKIN' STRESSES ($P + Q + F_1$) (CASE 7)

Heat Up (t = 12.0 seconds) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	-2,299	-1,029	-	1,893	1,251	-
B	-2,409	-638	-	1,742	1,928	-
C	-9,663	-4,970	-	8,496	2,778	-
D	-9,924	-5,267	-	8,748	2,715	-
E	2,900	-8,592	-	-1,084	-3,587	-
F	-1,500	-9,444	-	-2,150	34	-
G	-3,205	4,035	-	2,937	-2,753	-
H	14,616	23,468	-	-30,172	-9,000	-
I	24,816	13,262	-	-16,209	-27,771	-
J	18,352	23,870	-	-22,504	-27,294	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.3-10 THERMAL 'SKIN' STRESSES ($P + Q + F_1$) (CASE 8)

(Normal Operation) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	-11	-364	-	2	-303	-
B	-648	187	-	625	556	-
C	-3,833	-1,791	-	3,673	698	-
D	-3,936	-1,936	-	3,773	645	-
E	5,932	-3,610	-	-2,775	-4,261	-
F	5,453	483	-	-4,590	-2,492	-
G	15	8,293	-	1,181	214	-
H	5,573	20,891	-	-22,570	-758	-
I	20,091	4,523	-	-4,088	-21,360	-
J	8,568	12,150	-	-7,694	-16,972	-

Sections Illustrated in Figure 4.2.1-1.

TABLE 4.3-11 MEMBRANE PLUS BENDING PLUS SKIN STRESSES (P + Q + F_1)

(Pressure Case) All stresses in psi

Section	Inside			Outside		
	σ_ϕ	σ_θ	σ_r	σ_ϕ	σ_θ	σ_r
A	1,052	4,978	-1,000	3,632	5,220	-
B	436	8,436	-1,000	4,394	8,637	-
C	931	7,954	-1,000	3,923	7,946	-
D	981	7,886	-1,000	3,872	7,859	-
E	8,103	5,982	-1,000	-1,426	2,662	-
F	6,096	7,719	-1,111	4,690	6,545	-
G	-969	3,700	-1,111	9,036	5,931	-1,000
H	3,202	-1,367	-1,111	2,284	-1,551	-1,000
I	3,290	-1,376	-1,111	2,152	-1,620	-1,000
J	5,311	-1,231	-1,111	543	-2,479	-1,000

Sections Illustrated in Figure 4.2.1-1.

4.3.3 Usage Calculations. Using the total alternating stress levels found in Table 4.3-2, the fatigue usage factor can be solved. From the design specification (Reference 6.1), there are 1,500 thermal cycles and it is assumed there are 10 seismic cycles. Using Figures I-9.2 and I-9.1 from Reference 6.2, the fatigue usage factors are found. Table 4.3.3-1 contains these calculations. Notice, the stress ranges must be adjusted to the elastic modulus of the fatigue curves. The total usage factors are as follows.

Location	Fatigue Usage
A	0.0016
B	0.0257
C	0.0609
D	0.0609
E	0.233
F	0.2789
G	0.4065
H	0.4074
I	0.2006
J	0.0556

TABLE 4.3.3-1 CALCULATION OF FATIGUE USAGE

Location	S_{alt_1}* (ksi)	Elastic** Modulus Factor	S_{A_1}* (ksi)	Allow. Cycles	Usage Factor	S_{alt_2}* (ksi)	Elastic** Modulus Factor	S_{A_2}* (ksi)	Allow. Cycles	Usage Factor
A	18.42	1.042	19.2	10^5	0.0001	11.34	1.042	11.9	10^6	0.00149
B	30.6	1.103	33.8	13,000	0.0008	19.91	1.103	22.0	60,000	0.0249
C	36.8	1.103	40.6	8,000	0.0013	26.0	1.103	28.7	25,000	0.0596
D	37.0	1.103	40.9	8,000	0.0013	26.2	1.103	28.9	25,000	0.0596
E	51.9	1.103	57.3	2,750	0.0037	38.8	1.103	42.8	6,500	0.2293
F	66.6	1.103	73.5	1,250	0.0080	41.9	1.103	46.3	5,500	0.2709
G	73.1	1.103	80.7	1,100	0.0091	46.5	1.103	51.3	3,750	0.3974
H	74.8	1.103	82.6	1,000	0.0100	47.4	1.103	52.3	3,750	0.3974
I	121.4	0.968	119.7	700	0.0143	65.7	0.968	64.8	8,000	0.1863
J	93.6	0.968	92.3	1,700	0.0059	48.2	0.968	47.6	30,000	0.0491

* Subscript 1 for Seismic; Subscript 2 for no seismic loads.

** For carbon steel fatigue curve, $E = 30 \times 10^6$ psi; for stainless steel fatigue curve, $E = 26 \times 10^6$ psi

4.3.4 High Cycle Fatigue. The cumulative high cycle fatigue usages due to rapid cycling was determined to be as follows (Reference 6.12).

U = 0.000063

4.3.5 Accumulated Fatigue Usage. The extisting nozzle and remaining part of the safe end have accumulated a fatigue usage of 0.22 (Reference 6.1).

4.3.6 Total Fatigue Usage. The total fatigue usage is as follows.

Location	System Fatigue	High Cycle	Existing Fatigue	Total Usage
A	0.0016	0.0001	0.22	0.2217
B	0.0257	0.0001	0.22	0.2458
C	0.0609	0.0001	0.22	0.2810
D	0.0609	0.0001	—	0.0610
E	0.233	0.0001	—	0.2331
F	0.2789	0.0001	—	0.2790
G	0.4085	0.0001	—	0.4086
H	0.4099	0.0001	—	0.4100
I	0.2006	0.0001	—	0.2007
J	0.0556	0.0001	—	0.0557

5. RESULTS

Detailed stress analysis of the feedwater nozzle and safe end assembly shows that the nozzle and assembly fully meet the ASME Code (Reference 6.2) stress intensity limits. Further, the nozzle and assembly are shown to satisfy the requirements for cyclic operation, with the maximum cumulative fatigue usage determined to be:

$$U_{max} = 0.41$$

6. REFERENCES

6.1 'Reactor Vessel System Cycling', Design Specification 22A6996, Rev. 0.

6.2 ASME Boiler and Pressure Vessel Code, Section III, Subsections NA and NB, 1977 Edition including Addenda through Summer 1978.

6.3 'ANSYS, Engineering Analysis System, User's Manual,' Swanson Analysis Systems, Inc.

6.4 Kreith, F., 'Principles of Heat Transfer', Third Edition, IEP Publisher, 1973.

6.5 DRF# B13-909, Monticello Feedwater Nozzle Stress Analysis Design Record File.

6.6 'Tentative Structural Design Basis for Reactor Pressure Vessels and Directly Associated Components', 1958.

6.7 GE Drawing No. 769E531, Rev. 0, As-Built Feedwater Nozzle.

6.8 GE Drawing No. 105D6009, Rev. 2, Thermal Sleeve

6.9 GE Drawing No. 137C7841, Rev. 1, Reducing Tee

6.10 GE Drawing No. PDS-3108, Layout.

6.11 GE Drawing No. 137C7843, Rev. 2, Safe End.

6.12 Reactor Vessel Rapid Cycling, GE Document No. 22A7227, Rev. 0.

6.13 GE Drawing No. 112D2892, Rev. 3, Safe End Assembly.

6.14 J.E. Shigley, Mechanical Engineering Design, McGraw-Hill, Second Edition, 1972.

APPENDIX 10 LISTING OF 'NONO'

```
10      REAL MEMSTR
20      REAL NEWSTR
30      REAL NUAVGS
40      REAL NUDIS
50      REAL MOMARM
60      REAL MOMENT
70      DIMENSION NELM(25),CORDX(27),STRS(27),DISAVG(27),STAVG(27),TSTR(27),
80&     NEWSTR(27),NUAVGS(27),NUDIS(27),MOMARM(27),MOMENT(27),KOUNT(999)
90      PRINT:""
100      PRINT:""
110      PRINT:""
120      PRINT:"DO YOU NEED INSTRUCTIONS?                (1=YES,0=NO)"
130      READ: NOYESO
140      IF(NOYESO.EQ.0) GOTO 10
150      PRINT:""
160      PRINT:""
170      PRINT:""
180      PRINT:""
190      PRINT:"THIS PROGRAM LINEARIZES THE STRESSES THROUGH THE "
200      PRINT:""
210      PRINT:"THICKNESS OF A SECTION."
220      PRINT:""
230      PRINT:"INPUT THE  LOCATION OF THE POINTS WHERE STRESSES ARE"
240      PRINT:""
250      PRINT:"ACTING, I.E. THE FIRST SURFACE, THE CENTROIDS AND"
260      PRINT:""
270      PRINT:"THE SECOND SURFACE."
280      PRINT:""
290      PRINT:"INPUT STRESSES AT THE FIRST SURFAFE, CENTROIDS AND "
300      PRINT:""
310      PRINT:"THE SECOND SURFACE."
320      PRINT:""
330      PRINT:" IF N IS THE NUMBER OF ELEMENTS THEN TOTAL STRESS AND"
340      PRINT:""
350      PRINT:"LOCATION ENTERIES REQUIRED ARE N+2, (I.E. 2 SURFACES"
360      PRINT:""
370      PRINT:"AND N CENTROIDS.)"
380      PRINT:""
390      PRINT:"THE PROGRAM THEN COMPUTES THE MEMBRANE STRESS BY"
400      PRINT:""
410      PRINT:"THE EQUIVALENT AREA METHOD."
420      PRINT:""
430      PRINT:"THE BENDING STRESSES ARE COMPUTED BY LINEARIZING THE"
440      PRINT:""
450      PRINT:"MOMENT ACROSS THE SECTION THICKNESS."
460      PRINT:""
470      PRINT:"PEAK STRESSES ARE THE TOTAL STRESS MINUS THE"
480      PRINT:""
490      PRINT:"MEMBRANE AND BENDING STRESSES AT THE SURFACES."
500      PRINT:""
501      PRINT:""
```

APPENDIX 10 (Continued)

```
      PRINT:""
      PRINT:""
      PRINT:"WHEN FINISHED INPUT NUMBER OF ELEMENTS = 0 TO EXIT"
      PRINT:""
      PRINT:""
   10 PRINT:""
      PRINT:""
      PRINT:"WANT A LISTING OF THE INPUT STRS & COORDS., (1=YES.0=NO)"
      READ: NOYES
      DO 300 L=1,999
      PRINT:" "
      PRINT:" "
      NSTRS=0
      PRINT:" INPUT NO. OF ELEM ACROSS THCK "
      READ: NEL
      IF(NEL.LE.0)GOTO 301
      LOCATE=NEL+2
      KOUNT(L)=L
      IF(KOUNT(L).EQ.1) GOTO 11
      PRINT:""
      PRINT:""
      PRINT:"USE COORDS. FROM THE PREVIOUS RUN?? (YES=1.NO=0)"
      READ: NOYES1
      IF(NOYES1.EQ.0) GOTO 11
      GOTO 12
   11 PRINT: " INPUT COORD. LOCATIONS X1,X2,...ETC. "
      READ: (CORDX(I),I=1,LOCATE)
C
   12 PRINT:" INPUT CORRES STRESSES "
      NSTRS=LOCATE
      READ: (STRS(J),J=1,NSTRS)
      TOTSTR=0.
      TOTDIS=0.
      DO 100 K=1,(NSTRS-1)
      STAVG(K)=(STRS(K)+STRS(K+1))/2.0
      DISAVG(K)=(CORDX(K+1)-CORDX(K))
      TSTR(K)= STAVG(K)*DISAVG(K)
      TOTSTR=TOTSTR+TSTR(K)
      TOTDIS=TOTDIS+DISAVG(K)
  100 CONTINUE
      MEMSTR=TOTSTR/TOTDIS
      TOTMOM=0.
```

APPENDIX 10 (Continued)

```
      DO 101 I=1,NSTRS
  101 NEWSTR(I)=STRS(I)-MEMSTR
      DO 102 I=1,(NSTRS-1)
      NUAVGS(I)=(NEWSTR(I)+NEWSTR(I+1))/2.0
      NUDIS(I)= CORDX(I+1)-CORDX(I)
      MOMARM(I)=(CORDX(I)-CORDX(1))+(CORDX(I+1)-CORDX(I))/2.
      MOMENT(I)=NUAVGS(I)*NUDIS(I)*MOMARM(I)
      TOTMOM= TOTMOM+MOMENT(I)
  102 CONTINUE
      SBEND=(6*TOTMOM)/(TOTDIS*TOTDIS)
      SBEND1=ABS(SBEND)
      SBEND2=SBEND1*(-1.)
      SBEND=ABS(SBEND)
      IF(STRS(1).LT.STRS(NSTRS)) GO TO 400
      PEAKS1=STRS(1)-MEMSTR-SBEND1
      PEAKS2=STRS(NSTRS)-MEMSTR-SBEND2
      GO TO 401
  400 PEAKS1=STRS(1)-MEMSTR-SBEND2
      PEAKS2=STRS(NSTRS)-MEMSTR-SBEND1
  401 IF(NOYES.EQ.0) GOTO 20
      PRINT:" "
      PRINT:"INPUT STRESSES ARE:"
      PRINT:" "
      WRITE(06,202)(STRS(I),I=1,NSTRS)
      PRINT:""
      PRINT:""
      PRINT:"INPUT COORD. ARE:"
      PRINT:""
      WRITE(06.203)(CORDX(I),I=1,LOCATE)
   20 WRITE(06,200) MEMSTR,SBEND.PEAKS1,PEAKS2
  300 CONTINUE
  301 WRITE(06,204)
  200 FORMAT(//,4X,"MEMBRANE STRESS = ",F10.1,4X,
&        "BENDING STRESSES =(+ OR-) ",F10.1,//.4X,
&       ,"PEAKS1 =".F10.1,4X."PEAKS2 =".F10.1.//)
  202 FORMAT(4X.4F10.1./)
  203 FORMAT(4X,4F10.3./)
  204 FORMAT(//,"          HAVE A NICE  DAY  !!          ".//)
      STOP
      END
```

APPENDIX 20 INTERGRANULAR STRESS CORROSION INDEX CALCULATION

The areas requiring an IGSCC stress rule index calculation are Sections C/D and H/I. These sections are at new weld locations.

20.1 Sections C and D

$$S.I. = \frac{P_m + P_B}{S_y} + \frac{Q + F + RESID}{S_y + 0.002E}$$

Section C is SA-508 (Class 1) carbon steel and Section D is SA-350 (LF2) carbon steel.

20.1.1 Mechanical Load Stress. The mechanical load stresses are the result of dead weight, thermal, and hydraulic loads during normal operation. The loads are obtained from Reference 6.1, and are as follows.

Nozzle Loads

Dead Weight (Nozzle 'A' Loads used)

F_x = −0.11 kip m_x = +11.6 in-kip

F_y = −0.63 kip m_y = −14.1 in-kip

F_z = +0.15 kip m_z = −11.1 in-kip

Thermal (Nozzle 'B' Loads used)

F_x = +0.82 kip m_x = +267.2 in-kip

F_y = −4.34 kip m_y = +66.7 in-kip

F_z = +1.37 kip m_z = +1.4 in-kip

20.1.1 (Continued)

Thermal Sleeve Loads

Dead Weight Plus Hydraulic

$F_y = -0.3$ kip

$F_z = -3.0$ kip

$m_x = -1.2$ in-kip

Thermal

$F_z = -1.2$ kip

The same procedure used in Section 3 will be used here. If more detail is required, refer to Section 3 for a reference.

$$P = (F_x^2 + F_y^2)^{1/2}$$

$$m = (m_x^2 + m_y^2 + m_z^2)^{1/2}$$

Nozzle Loads

Dead Weight

$P = 0.64$ kip

$m = 21.4$ in-kip

$F_z = 0.15$ kip

Thermal

$P = 4.42$ kip

$m = 275.41$ in-kip

$F_z = 1.37$ kip

20.1.1 (Continued)

Thermal Sleeve Loads

Dead Weight plus Hydraulic

$P = 0.3$ kip

$m = 1.2$ in-kip

$F_z = 3.0$ kip

Thermal

$F_z = 1.2$ kip

Section C and D

Nozzle Load Stresses

Dead Weight

$m = 21.4 + 0.64(7.47) + 0.15\ (0.56) = 26.27$ in-kip

$$\sigma_{BEND} = \frac{m}{z} = \frac{26.27}{51.98} = 0.506 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{0.15}{19.03} = 0.008 \text{ ksi}$$

Thermal

$m = 275.41 + 4.42(7.47) + 1.37(0.56) = 309.2$ in-kip

$$\sigma_{BEND} = \frac{m}{z} = \frac{309.2}{51.98} = 5.95 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{1.37}{19.03} = 0.72 \text{ ksi}$$

20.1.1 (Continued)

Thermal Sleeve Stresses

Dead Weight plus Hydraulic

$$m = 1.2 + 0.3(21.12) + 3.0(2.36) = 14.62 \text{ in-kip}$$

$$\sigma_{BEND} = \frac{m}{z} = \frac{14.62}{51.98} = 0.282 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = \frac{3}{19.03} = 0.158 \text{ ksi}$$

Thermal

$$m = 1.2(2.36) = 2.84 \text{ in-kip}$$

$$\sigma_{BEND} = \frac{m}{z} = 0.055 \text{ ksi}$$

$$\sigma_{AX.} = \frac{F_z}{A} = 0.063 \text{ ksi}$$

Total Stresses. Primary stresses are dead weight and hydraulic stresses, while secondary stresses are thermal load stresses.

Primary Stress

$$\sigma_{\phi} = \sigma_{BEND} + \sigma_{AX} = 0.954 \text{ ksi}$$

Secondary Stress

$$\sigma_{\phi} = \sigma_{BEND} + \sigma_{AX} = 6.14 \text{ ksi}$$

20.1.2 Pressure Stress

Prim... Pressure Stress

$$\sigma_\theta = \frac{Pri}{t} = \frac{1,000(10,875)}{2(0.531)} = 10.24 \text{ ksi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 5.12 \text{ ksi}$$

$$\sigma_r = -1,000 \text{ psi}$$

Secondary Pressure Stress. The stresses in Table 4.2-9 are the P+Q pressure stresses corrosion not included. The primary stress (corrosion not included) is expected to be as follows.

$$\sigma_\theta = 8,600 \text{ psi}$$

$$\sigma_\phi = 4,300 \text{ psi}$$

The actual stress from Table 4.2-9 is given as

Section C	Section D
$\sigma_\theta = 7,931$ psi	$\sigma_\theta = 7,846$ psi
$\sigma_\phi = 3,837$ psi	$\sigma_\phi = 3,790$ psi

Therefore, the secondary pressure stresses are as follows.

Section C	Section D
$\sigma_\theta = -669$ psi	$\sigma_\theta = -754$ psi
$\sigma_\phi = -463$ psi	$\sigma_\phi = -510$ psi

20.1.3 Thermal Stresses. The thermal stresses given in Table 4.2-8 for steady state normal operation are:

Section C	Section D
σ_θ = 674 psi	σ_θ = 619 psi
σ_ϕ = 3,470 psi	σ_ϕ = 3,563 psi

20.1.4 Peak Stresses. The peak stresses are obtained for both the pressure and thermal cases by comparing Tables 4.2-8 and 4.2-9 to 4.2-17 and 4.2-18, respectively. The total peak stress is the addition of these two values.

Section C	Section D
σ_θ = 203 + 86 = 289 psi	σ_θ = 210 + 82 = 292 psi
σ_ϕ = 24 + 15 = 39 psi	σ_ϕ = 26 + 13 = 39 psi

The peak stresses due to mechanical loads are small and, therefore, are not included.

20.1.5 Index Calculation

Stress Summary:

* $\pm$ refers to locations 180° apart

Primary Stresses

Loading	σ_θ ksi	σ_ϕ (ksi)	σ_r (ksi)
Mechanical Load	—	$\pm$ 0.954*	--
Pressure	10.24	5.12	-1.0
TOTAL	10.24	6.074/4.166	-1.0

20.1.5 (Continued)

Secondary Stresses

Loading / Sections	σ_θ ksi (C)	σ_θ ksi (D)	σ_ϕ (ksi) (C)	σ_ϕ (ksi) (D)	σ_r (ksi)
Mechanical Load	—		± 6.14*		—
Pressure	−0.67	−0.76	−0.46	−0.51	—
Thermal	0.67	0.62	3.47	3.57	—

	Section C	Section D
TOTAL	σ_θ = --	σ_θ = −0.14 ksi
	σ_ϕ = 9.15/−3.13 ksi	σ_ϕ = 9.2/−3.08 ksi

Peak Stresses

Section C	Section D
σ_θ = 0.04 psi	σ_θ = 0.04 psi
σ_ϕ = 0.29 psi	σ_ϕ = 0.29 psi

For,

SA-350 (FL2) Carbon Steel

S_y = 27.85 ksi

E = 26.0 x 10^3 ksi

RESID = 37 ksi

SA-508 (Class 1) Carbon Steel

S_y = 27.1 ksi

E = 26.0 x 10^3 ksi

RESID = 37 ksi

20.1.5 (Continued)

For Section C

Based on Stress Intensities

$P_m + P_B = 11.24$ ksi

Q+F: The two possible stress intensities are based on the following stress components:

Comb	σ_ϕ (ksi)	σ_θ (ksi)	
1	0.04	9.44	$(Q+F)_{max} = 9.44$ ksi
2	0.04	-2.84	

Therefore,

$$S.I. = \frac{11.24}{27.1} = \frac{9.44 + 37}{27.1 + 52}$$

$$= 0.4148 + 0.5871 = 1.0019$$

Now, since S.I. > 1.0, allowed, the S.I. is recalculated based on positive principle stresses.

Based on Positive Principle Stresses

$P_m + P_B = 10.24$ ksi

$Q + F = 9.44$ ksi

$$S.I. = \frac{10.24}{27.1} = \frac{9.44 + 37}{27.1 + 52}$$

$$= 0.3779 + 0.5871 = 0.965 < 1.0 \text{ allowed}$$

By inspection, the S.I. at Section C is higher than that at Section D.

20.2 Sections H and I. Section H is SA-350 (LF2) carbon steel and Section I is SA-351 (CF3) stainless steel.

20.2.1 Section H

20.2.1.1 Mechanical Load Stress. The mechanical load stresses are the result of dead weight, thermal, and hydraulic loads during normal operation. The loads are obtained from Reference 6.1. Note, in Paragraph 20.1.1 of this appendix, the mechanical loads were reduced to:

Nozzle Loads

$P = 0.64$ kip (Dead Weight)

$m = 21.4$ in-kip

$F_z = 0.15$ kip

$P = 4.42$ kip (Thermal)

$m = 275.41$ in-kip

$F_z = 1.37$ kip

Thermal Sleeve Loads

$P = 0.3$ kip (Dead Weight and Hydraulic)

$m = 1.2$ in-kip

$F_z = 3.0$ kip

$F_z = 1.2$ kip (Thermal)

The same procedure used in Section 3 will be used here. If more detail is required, refer to Section 3 for a reference.

20.2.1.1 (Continued)

Thermal Sleeve Load Stresses

Dead Weight

$$m = 1.2 + 0.3(20.12) = 7.24 \text{ in-kip}$$

$$\sigma_{BEND} = \frac{m}{z} = \frac{7.24}{22.32} = 0.325 \text{ ksi}$$

$$\sigma_{AX} = \frac{F_z}{A} = \frac{3}{10.46} = 0.287 \text{ ksi}$$

Nozzle Load Stress

Dead Weight

$$m = 21.4 + 0.64(8.47) + 0.15(1.8) = 27.09 \text{ in-kip}$$

$$\sigma_{BEND} = 0.381 \frac{m}{z} = (0.381) \frac{27.09}{22.32} = 0.463 \text{ ksi}$$

$$\sigma_{AX} = 0.381 \frac{F_z}{A} = (0.381) \frac{0.15}{10.46} = 0.006 \text{ ksi}$$

Thermal

$$m = 275.41 + 4.42(8.47) + 1.37(1.8) = 315.32 \text{ in-kip}$$

$$\sigma_{BEND} = 0.381 \frac{m}{z} = (0.381) \frac{315.32}{22.32} = 5.39 \text{ ksi}$$

$$\sigma_{AX} = 0.381 \frac{F_z}{A} = (0.381) \frac{1.37}{10.46} = 0.050 \text{ ksi}$$

Total Stresses. Primary stresses are dead weight and hydraulic stresses, while secondary stresses are thermal load stresse...

Primary Stresses

$$\sigma_\phi = \sigma_{BEND} + \sigma_{AX} = 1.081 \text{ ksi}$$

Secondary Stresses

$$\sigma_\phi = \sigma_{BEND} + \sigma_{AX} = 5.555 \text{ ksi}$$

20.2.1.2 Pressure Stresses

Primary Pressure Stress

$$\sigma_\theta = \frac{PD_i}{2t} = \frac{111(8.505)}{2(0.375)} = 1.26 \text{ ksi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 0.63 \text{ ksi}$$

$$\sigma_r = -0.111 \text{ ksi}$$

Secondary Pressure Stress. The stresses in Table 4.2-9 are the P+Q pressure stresses corrosion not included. The primary stress (corrosion not included) is expected to be:

$$\sigma_\theta = 0.93 \text{ ksi}$$

$$\sigma_\phi = 0.465 \text{ ksi}$$

The actual stress from Table 4.2-9 is given as:

$$\sigma_\theta = -1.38 \text{ ksi}$$

$$\sigma_\phi = 3.19 \text{ ksi}$$

Therefore, the secondary pressure stresses are as follows:

$$\sigma_\theta = -2.31 \text{ ksi}$$

$$\sigma_\phi = 2.73 \text{ ksi}$$

20.2.1.3 Thermal Stresses. The thermal stresses given in Table 4.2-8 for steady state normal operation are:

$$\sigma_\theta = 25.12 \text{ ksi}$$

$$\sigma_\phi = 12.08 \text{ ksi}$$

20.2.1.4 Peak Stresses. The peak stresses are obtained for both the pressure and thermal cases by comparing Table 4.2-8 and 4.2-9 to 4.2-17 and 4.2-18 respectively. The total peak stress is the addition of these two values.

$$\sigma_{\theta} = -4.22 - 0.011 = -4.231 \text{ ksi}$$

$$\sigma_{\phi} = -6.5 + 0.013 = -6.49 \text{ ksi}$$

The peak stresses due to mechanical loads are small and therefore are not included.

20.2.1.5 Index Calculation

Stress Summary:

* ± refers to locations 180° apart

Primary Stresses

Loading	σ_{θ} ksi	σ_{ϕ} (ksi)	σ_r (ksi)
Mechanical Load	—	± 1.081*	—
Pressure	1.26	0.63	-0.111
TOTAL	1.26	1.711/0.451	-0.111

Secondary Stresses

Loading	σ_{θ} ksi	σ_{ϕ} (ksi)	σ_r (ksi)
Mechanical Load	—	± 5.555*	--
Pressure	-2.31	2.73	—
Thermal	25.12	12.08	—
TOTAL	22.81	20.365/9.255	—

20.2.1.5 (Continued)

Peak Stresses

$$\sigma_\theta = -4.231 \text{ ksi}$$

$$\sigma_\phi = -6.49 \text{ ksi}$$

For SA-350 (LF2) Carbon Steel

$$S_y = 27.85 \text{ ksi}$$

$$E = 26.0 \times 10^3 \text{ ksi}$$

$$\text{RESID} = 39.5 \text{ ksi}$$

Therefore, based on stress intensities

$$SI = \frac{1.822}{27.85} + \frac{22.81 - 4.231 + 39.5}{27.85 + 52}$$

$$= 0.0655 + 0.7274 = 0.7929 < 1.0 \text{ allowed}$$

20.2.2 Section I

20.2.2.1 Mechanical Load Stress

Thermal Sleeve Load Stresses

Dead Weight

$$m = 1.2 + 0.3(20.12) = 7.24 \text{ in-kip}$$

$$\sigma_{BEND} = \frac{m}{z} = \frac{7.24}{29.07} = 0.249 \text{ ksi}$$

$$\sigma_{AX} = \frac{F_z}{A} = \frac{3}{13.78} = 0.218 \text{ ksi}$$

Thermal

$$\sigma_{AX} = \frac{F_z}{A} = \frac{1.2}{13.78} = 0.087 \text{ ksi}$$

20.2.2.1 (Continued)

Nozzle Load Stresses

Dead Weight

$$m = 21.4 + 0.64(8.47) + 0.15(1.8) = 27.09 \text{ in-kip}$$

$$\sigma_{BEND} = 0.381 \frac{m}{z} = (0.381)\frac{27.09}{29.07} = 0.355 \text{ ksi}$$

$$\sigma_{AX} = 0.381 \frac{F_z}{A} = (0.381)\frac{0.15}{13.78} = 0.005 \text{ ksi}$$

Thermal

$$m = 275.41 + 4.42(8.47) + 1.37(1.8) = 315.32 \text{ in-kip}$$

$$\sigma_{BEND} = 0.381 \frac{m}{z} = (0.381)\frac{315.32}{29.07} = 4.133 \text{ ksi}$$

$$\sigma_{AX} = 0.381 \frac{F_z}{A} = (0.381)\frac{1.37}{13.78} = 0.038 \text{ ksi}$$

Total Stresses

Primary Stresses

$$\sigma_\phi = \sigma_{BEND} = \sigma_{AX} = 0.827 \text{ ksi}$$

Secondary Stresses

$$\sigma_\phi = \sigma_{BEND} = \sigma_{AX} = 4.258 \text{ ksi}$$

20.2.2.2 Pressure Stresses

Primary Pressure Stress

$$\sigma_\phi = \frac{PD_i}{2t} = \frac{111(8.386)}{2(0.494)} = 0.943 \text{ ksi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 0.471 \text{ ksi}$$

$$\sigma_r = -0.111 \text{ ksi}$$

20.2.2.2 (Continued)

Secondary Pressure Stress. The stresses in Table 4.2-9 are the P+Q pressure stresses corrosion not included. The primary stress (corrosion not included) is expected to be:

$\sigma_\theta = 0.93$ ksi

$\sigma_\phi = 0.465$ ksi

The actual stress from Table 4.2-9 is given as:

$\sigma_\theta = -1{,}381$ psi

$\sigma_\phi = 3{,}289$ psi

Therefore, the secondary pressure stresses are as follows:

$\sigma_\theta = -2.311$ ksi

$\sigma_\phi = 2.824$ ksi

20.2.2.3 Thermal Stresses. The thermal stresses given in Table 4.2-8 for steady state normal operation are:

$\sigma_\theta = -1.322$ ksi

$\sigma_\phi = 12.77$ ksi

20.2.2.4 Peak Stresses. The peak stresses are obtained for both the pressure and thermal case by comparing Tables 4.2-8 and 4.2-9 to 4.2-17 and 4.2-18 respectively. The total peak stress is the addition of these two values.

$\sigma_\theta = 5.845 + 0.005 = 5.85$ ksi

$\sigma_\phi = 7.323 + 0.001 = 7.324$ ksi

20.2.2.5 Index Calculations

Stress Summary:

* $\pm$ refers to locations 180° apart

20.2.2.5 (Continued)

Primary Stresses

Loading	σ_θ ksi	σ_ϕ (ksi)	σ_r (ksi)
Mechanical Load	—	± 0.827*	—
Pressure	0.943	0.471	−0.111
TOTAL	0.943	1.298/−0.356	−0.111

Secondary Stresses

Loading	σ_θ ksi	σ_ϕ (ksi)	σ_r (ksi)
Mechanical Load	—	± 4.258	—
Pressure	−2.311	2.824	—
Thermal	−1.322	12.77	—
TOTAL	−3.633	19.852/11.336	—

Peak Stresses

σ_θ = 5.85 ksi

σ_ϕ = 7.324 ksi

For SA-351 (CF3) Stainless Steel

S_y = 17.75 ksi

$E = 25.7 \times 10^3$ ksi

RESID = 27.5 ksi

Therefore, based on stress intensities,

$$SI = \frac{1.409}{17.75} + \frac{27.176 + 27.5}{17.75 + 51.4}$$

$$= 0.0794 + 0.7907 = 0.8701 < 1.0 \text{ allowed}$$

20.3 Conclusion. All stress indices are less than allowable of 1.0. The calculated indices are as follows.

Location	S. I. (1)	S. I. (2)
C	1.002	0.965
H	0.7929	—
I	0.8701	—

(1) Based on Stress Intensities

(2) Based on Positive Principle Stresses

APPENDIX 30 RECALCULATIONS REQUIRED DUE TO MANUFACTURING DEVIATIONS

This attachment analyzes the effects of the manufacturing deviations on the feedwater safe end and thermal sleeve. The deviations are described in detail in DDR Numbers 15139, 26521, and 15127, dated April 29, 1981, July 2, 81, and May 7, 1981, respectively.

30.1 Deviations Due to DDR Number 15127. The deviations reported within DDR Number 15127 are two undersize locations on the thermal sleeve pads. The undersize amounts are two mils and four mils on the 7.812 inch diameter and the 7.625 inch diameter, respectively. It is noted, however, that the deviations are on the thermal sleeve pads, and within the previous calculations the pads are neglected conservatively. Therefore, these deviations will have no effect on the previous analysis and will not require recalculations of stresses.

30.2 Deviations Due to DDR Number 26521. The deviation reported in DDR Number 15140 is a tool undercut along the tapered surface between the 10.84 inch diameter zone and the 12.00 inch diameter zone. However, this tool undercut was weld repaired, heat treated, and machined to original finish size. This type of repair is allowed per ASME Code, Reference 6.2. Post-weld heat treatment ensures stress relief and an acceptable metallurgical condition. The part is restored to the original specified dimensions. Therefore, these deviations will have no effect on the previous analysis and requires no recalculation of stresses.

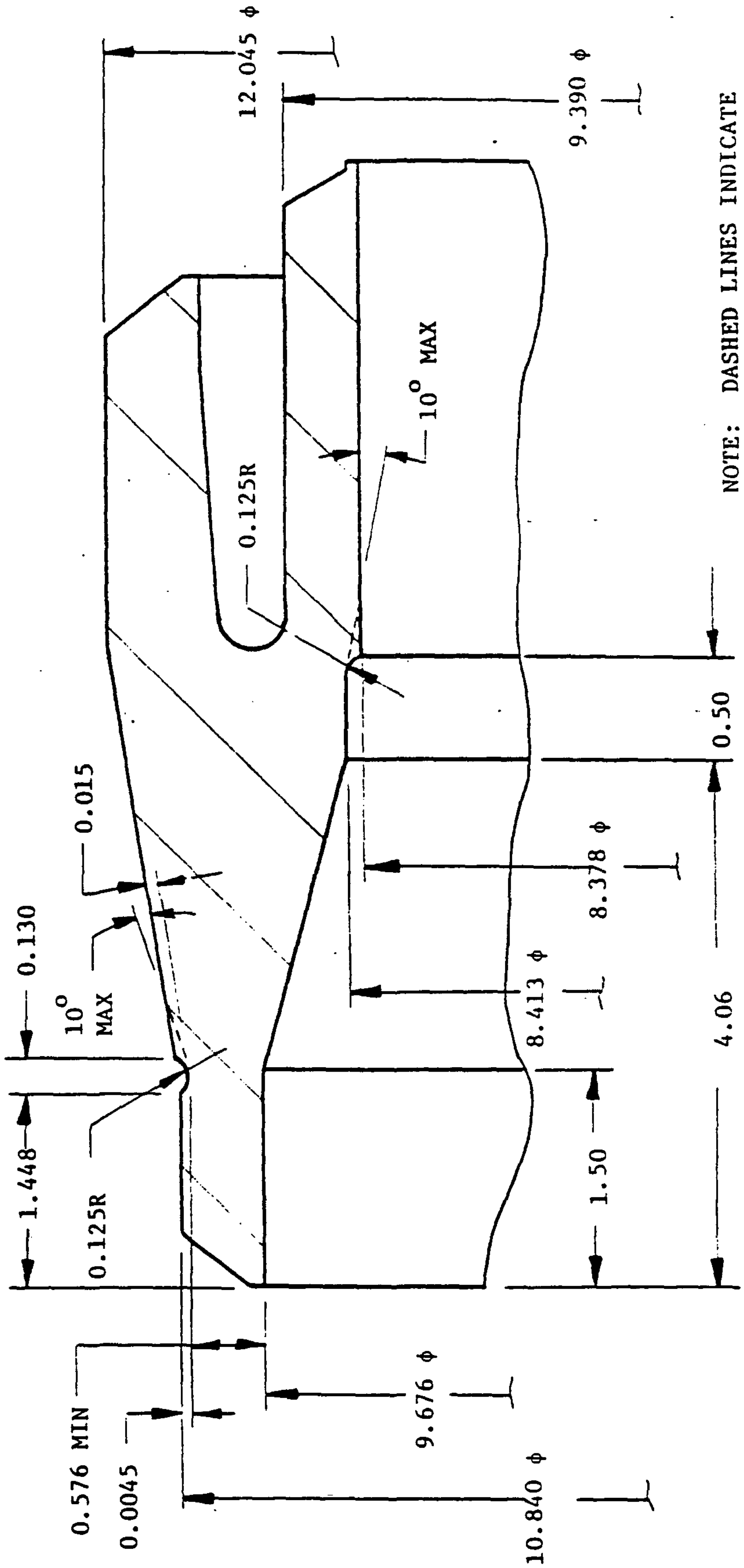
30.3 Deviations Due to DDR Number 15139. This paragraph analyzes the effects of two manufacturing deviations on the Monticello feedwater safe end. The deviations are described in detail in DDR Number 15139, dated April 30, 1981, and illustrated on Figure 30.3-1.

30.3.1 Summary of Results. The results obtained for these deviations are compared below with those from the previous nominal calculations.

TABLE 30.3.1-1 PRIMARY STRESS ANALYSIS

(All stresses in ksi)

		After Deviations		Before Deviations		Allowables	
Case	Location	Pm	Pm+B	Pm	Pm+B	Pm	Pm+B
Design	F	13.96	24.38	13.70	23.94	18.6	27.90
	G	2.83	14.90	2.74	14.54	18.6	27.90
Service Level C	F	15.36	33.89	15.07	33.28	27.85	41.77
	G	4.25	23.37	4.11	22.77	27.85	41.77



NOTE: DASHED LINES INDICATE REQUIRED BLENDING

FIGURE 30.3.1 DEVIATIONS DESCRIBED IN DDR NO. 15139

TABLE 30.3.1-2 PRIMARY PLUS SECONDARY STRESS ANALYSIS

(All stresses in ksi)

	After Deviations		Before Deviations		
Location	P + Q	P + Q*	P + Q	P + Q*	Allowable
F	62.3	37.23	61.68	36.61	55.8
G	62.82	45.94	62.29	45.42	55.8

* Thermal Bending Removed

TABLE 30.3.1-3 FATIGUE ANALYSIS

	After Deviation	Before Deviation
Location	Fatigue Usage	Fatigue Usage
F	0.439	0.279
G	0.41	0.409

30.3.2 Primary Stress Analysis

a. Section F (As Built)

$t = 0.576 \text{ in} - \underbrace{(1/32 \text{ in} + 1/16 \text{ in})}_{\text{corrosion}} = 0.4822 \text{ in}$

$D_o = 10.831 - 2(1/32) = 10.7685 \text{ in}$

$D_i = 9.679 + 2(1/16) = 9.804 \text{ in}$

$\text{Area} = 15.584 \text{ in}^2$

$Z = \frac{I}{C} = 38.365$

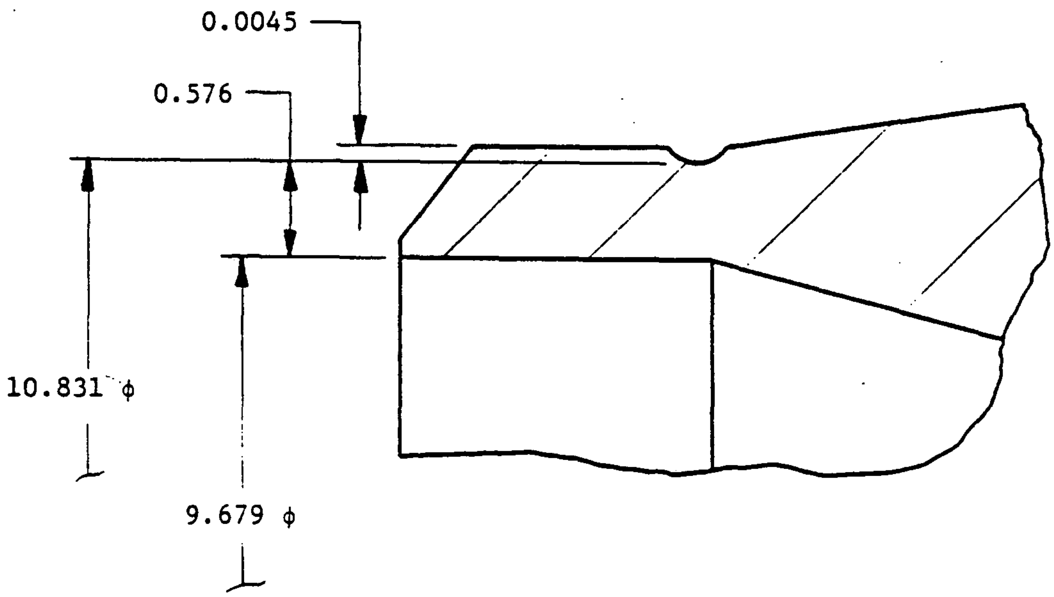


FIGURE 30.3.2.a SECTION F (AS BUILT)

30.3.2.a (Continued)

(1) Design Conditions

Design Pressure Stress

$$\sigma_\theta = \frac{1250(9.804)}{2(0.4822)} = 12,708 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 6354 \text{ psi}$$

$$\sigma_r = -1250 \text{ psi}$$

Stress Due to Nozzle Loads

P = 4.05 kip

M = 534.4 in-kip

F_z = 2.28 kip

M = 534.4 + 4.05(1.62) = 541 in-kip

$$\sigma_{BEND} = \frac{M}{Z} = \frac{541}{38.365} = 14.102 \text{ ksi}$$

$$\sigma_{AX} = \frac{F_t}{A} = \frac{2.28}{15.584} = 0.147 \text{ ksi}$$

Stress Due to Thermal Sleeve Loads

P = 2.57 kip

M = 3.124 in-kip

F_z = 5.7 kip

M = 3.124 + 2.54(26.97) + 5.7(1.8) = 82.7 in-kip

$$\sigma_{BEND} = \frac{M}{Z} = \frac{82.7}{38.365} = 2.156 \text{ ksi}$$

$$\sigma_{AX} = \frac{F_z}{A} = \frac{5.7}{15.584} = 0.366 \text{ ksi}$$

30.3.2.a.(1) (Continued)

Total Stress

$\sigma_\phi = 6{,}354 + 14{,}102 + 147 + 2{,}156 + 366 = 23{,}125$ psi

$\sigma_\theta = 12{,}708$ psi

$\sigma_r = -1250$ psi

(2) Service Level C Conditions

Service Level C Pressure Stress

$$\sigma_\theta = \frac{1375(9.804)}{2(0.4822)} = 13{,}978 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 6989 \text{ psi}$$

$\sigma_r = -1375$ psi

Stress Due to Nozzle Loads

$P = 6.44$ kip

$M = 789.3$ in-kip

$F_z = 4.61$ kip

$M = 789.3 + 6.44(1.62) = 799.8$ in-kip

$$\sigma_{BEND} = \frac{799.8}{38.365} = 20.847 \text{ ksi}$$

$$\sigma_{AX} = \frac{4.61}{15.584} = 0.296 \text{ ksi}$$

30.3.2.a.(2) (Continued)

Stress Due to Thermal Sleeve Loads

$P = 5.08$ kip

$M = 5.39$ in-kip

$F_z = 6.0$ kip

$M = 5.39 + 5.08(26.97) + 6.0(1.8) = 153.2$ in-kip

$$\sigma_{BEND} = \frac{153.2}{38.365} = 3.994 \text{ ksi}$$

$$\sigma_{AX} = \frac{6.0}{15.584} = 0.385 \text{ ksi}$$

Total Stress

$\sigma_\phi = 6989 + 20,847 + 296 + 3994 + 385 = 32,511$ psi

$\sigma_\theta = 13,978$ psi

$\sigma_r = -1375$ psi

(3) Thickness Requirement for Section F

Treating the safe end as a 'nozzle', the safe end thickness adjacent to the attaching pipe shall not be thinner than the greater of the pipe thickness or the quantity (S_{mp}/S_{mn}).

Where:

t_p = Pipe Nominal Thickness

S_{mp} = Pipe Allowable (S_m)

S_{mn} = Safe End Allowable (S_m)

30.3.2.a.(3) (Continued)

For our geometry;

$$\left.\begin{aligned} t_p &= 0.5405 \text{ in} \\ S_{mp} &= 18.1 \text{ ksi} \\ S_{mn} &= 18.6 \text{ ksi} \end{aligned}\right\} \quad t_p(S_{mp}/S_{mn}) = 0.526 \text{ in}$$

Assuming Section F is the safe end thickness,

Safe end thickness = 0.576 in > 0.5405 in

$\therefore$ CRITERIA MET

30.3.2 (Continued)

b. Section G (As Built)

$$t = \frac{(9.39 - 8.378)}{2} - \underbrace{(2 * 1/16)}_{\text{corrosion}} = 0.381 \text{ in}$$

$$t_{assumed} = \frac{(9.39 - 8.413)}{2} - \overbrace{(2 * 1/16)} = 0.3635 \text{ in}$$

$$D_o = 9.390 - 2(1/16) = 9.265 \text{ in}$$

$$D_i = 8.413 + 2(1/16) = 8.538 \text{ in}$$

$$\text{Area} = 10.166 \text{ in}^2$$

$$Z = \frac{I}{C} = 21.77 \text{ in}^3$$

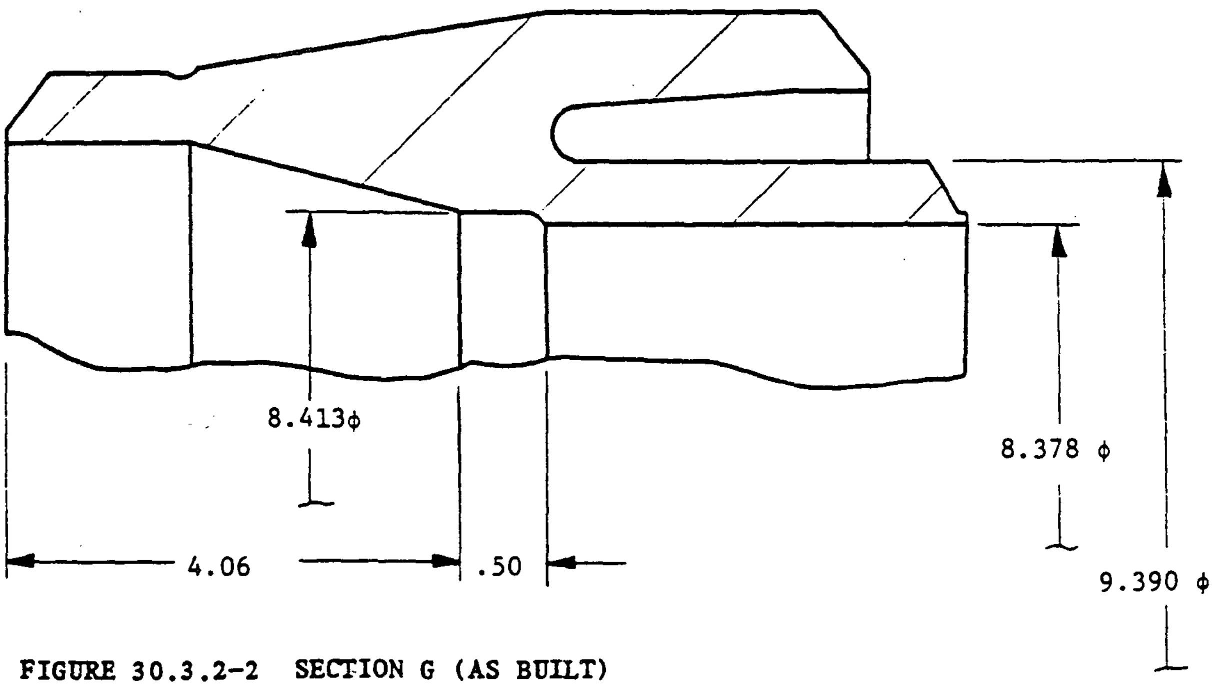


FIGURE 30.3.2-2 SECTION G (AS BUILT)

30.3.2.b (Continued)

(1) Design Conditions

Design Pressure Stress

$$\sigma_\theta = \frac{222(8.538)}{2(0.3635)} = 2,608 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 1304 \text{ psi}$$

$$\sigma_r = -222 \text{ psi}$$

Stress Due to Thermal Sleeve Loads

P = 2.57 kip

M = 3.124 in-kip

F_z = 5.7 kip

M = 3.124 + 2.57(23.87) = 64.47 in-kip

$$\sigma_{BEND} = \frac{64.47}{21.77} = 2.962 \text{ ksi}$$

$$\sigma_{AX} = \frac{5.7}{10.166} = 0.561 \text{ ksi}$$

Stress Due to Nozzle Loads

P = 4.05 kip

M = 534.4 in-kip

F_z = 2.28 kip

30.3.2.b(1) (Continued)

The same ratio used in the previous nominal calculations (Page 35) will be used here. This ratio simply accounts for the stiff nozzle influence.

$$M = 534.4 + 4.05(4.72) + 2.28(1.8) = 557.62 \text{ in-kip}$$

$$\sigma_{BEND} = (0.381)\frac{M}{Z} = (0.381)\frac{557.62}{21.77} = 9.759 \text{ ksi}$$

$$\sigma_{AX} = (0.381)\frac{F_z}{A} = (0.381)\frac{2.28}{10.166} = 0.086 \text{ ksi}$$

Total Stress

$$\sigma_\phi = 1304 + 2962 + 561 + 9759 + 86 = 14{,}672 \text{ psi}$$

$$\sigma_\theta = 2608 \text{ psi}$$

$$\sigma_r = -222 \text{ psi}$$

(2) Service Level 'C' Conditions

Service Level 'C' Pressure Stress

$$\sigma_\theta = \frac{333(8.538)}{2(0.3635)} = 3911 \text{ psi}$$

$$\sigma_\phi = \frac{\sigma_\theta}{2} = 1956 \text{ psi}$$

$$\sigma_r = -333 \text{ psi}$$

30.3.2.b.(2) (Continued)

Stress due to Thermal Sleeve

P = 5.08 kip

M = 5.39 in-kip

F_z = 6.0 kip

M = 5.39 + 5.08(22.87) = 126.65 in-kip

$$\sigma_{BEND} = \frac{M}{Z} = \frac{126.65}{21.77} = 5.818 \text{ ksi}$$

$$\sigma_{AX} = \frac{F_z}{A} = \frac{6.0}{10.166} = 0.591 \text{ ksi}$$

Stress Due to Thermal Sleeve

P = 6.44 kip

M = 789.3 in-kip

F_z = 4.61 kip

The same ratio used in the nominal calculations (Page 35) will be used here. This ratio simply accounts for the stiff nozzle influence on the thermal sleeve.

M = 789.3 + 6.44(4.72) + 4.61(1.8) = 828.0 in-kip

$$\sigma_{BEND} = 0.381 \frac{M}{Z} = (3.81) \frac{828}{21.77} = 14.491 \text{ ksi}$$

$$\sigma_{AX} = 0.381 \frac{F}{A} = (.381) \frac{4.61}{10.166} = 0.173 \text{ ksi}$$

Total stress

σ = 1956 + 5818 + 591 + 14,491 + 173 = 23,029 psi

σ = 3911 psi

σ_r = -333 psi

30.3.2 (Continued)

c. Summary

Condition	Section	P_m	P_m Allow	$P_m + P_B$	$P_m + P_B$ Allow
Design	F	13.96	18.6	24.38	27.90
Event	G	2.83	18.6	14.90	27.90
Service	F	15.36	27.85	33.89	41.77
Level 'C' Event	G	4.25	27.85	23.37	41.77

(All stresses in ksi)

All conditions are met for primary stress analysis.

30.3.3 Primary Plus Secondary Stress Analysis. This portion of the report discusses the detailed stress evaluation of the thermal stress, pressure stress, mechanical stress, stress ranges, and fatigue usage for selected locations of the geometry.

30.3.3.1 Thermal Stress. Sections F and G are thinner than their corresponding sections in the previous nominal calculations. The reduction in thickness for these sections is 1.65 percent and 2.3 percent (Section F and G, respectively). This small change will have no significant effect on the heat transfer coefficients and thus will be directly proportional to the change in the biot's number. For Section F, the biot's numbers before and after the reduction are 1.067 and 1.0494, respectively. For Section G, the biot's numbers before and after are 1.1785 and 1.1514, respectively. For both sections, the biot number is in such a range that the small percentage change in it due to the thickness change will have no significant impact on the stresses in the region. This, along with the fact that, as the thicknesses are reduced, the relative stiffnesses are lowered, causing thermal stresses, which are secondary or displacement controlled stresses, to be lowered. Therefore, the stresses obtained in the previous nominal calculations will be conservatively used here.

30.3.3.2 Mechanical Load Stress. The stresses obtained by mechanical loading are recalculated to account for the reduced thicknesses.

Section F

Nozzle Loads (P + Q)

$P = 4.42$ kip

$M = 275.4$ in-kip

$F_z = 1.37$ kip

$M = 275.4 + 4.42\ (1.62)$

$= 282.56$ in-kip

$\sigma_{BEND} = \frac{282.56}{38.365} = 7.365$ ksi

$\sigma_{AX} = \frac{1.37}{15.584} = 0.088$ ksi

$P = \pm 3.136$ kip

$M = \pm 390.9$ in-kip

$F_z = \pm 0.26$ kip

$M = 390.9 + 3.136\ (1.62)$

$= 395.98$ in-kip

$\sigma_{BEND} = \frac{395.98}{38.365} = 10.322$ ksi

$\sigma_{AX} = \frac{.26}{15.584} = 0.017$ ksi

Thermal Sleeve Loads

$F_z = 3.7$ kip

$M = 3.7\ (1.8) = 6.66$ in-kip

$\sigma_{BEND} = \frac{6.66}{33.365} = 0.174$ ksi

$\sigma_{AX} = \frac{3.7}{15.584} = 0.238$ ksi

$P = \pm 2.52$ kip

$M = \pm 2.333$ in-kip

$F_z = \pm 1.5$ kip

$M = 2.333 + 2.52\ (26.97) + 1.5\ (1.8)$

$= 73.0$ in-kip

$\sigma_{BEND} = \frac{73.0}{38.365} = 1.903$ ksi

$\sigma_{AX} = \frac{1.5}{15.584} = 0.097$ ksi

Total Stress

$\sigma_{\phi_{BEND}} = 7{,}539$ psi $= \pm 12{,}225$ psi

$\sigma_{\phi_{AX}} = 326$ psi $= \pm 114$ psi

Section G (P + Q)

Nozzle Loads

$P = 4.42$ kip

$M = 275.4$ in-kip

$F_z = 1.37$ kip

$M = 275.4 + 4.42\ (4.72) + 1.37\ (1.8)$

$= 298.73$ in-kip

$$\sigma_{\phi_{BEND}} = (0.381)\ \frac{298.73}{21.77} = 5.229 \text{ ksi}$$

$$\sigma_{\phi_{AX}} = (0.381)\ \frac{1.37}{10.166} = 0.052 \text{ ksi}$$

$P = \pm\ 3.136$ kip

$M = \pm\ 390.9$ in-kip

$F_z = \pm\ 0.26$ kip

$M = 390.9 + 3.136\ (4.72) + 0.26\ (1.8)$

$= 406.17$ in-kip

$$\sigma_{\phi_{BEND}} = (0.381)\ \frac{406.17}{21.77} = 7.109 \text{ ksi}$$

$$\sigma_{\phi_{AX}} = (0.381)\ \frac{0.2}{10.166} = 0.010 \text{ ksi}$$

Thermal Sleeve Loads

$F_z = 3.7$ kip

$$\sigma_{AX} = \frac{3.7}{10.166} = 0.364 \text{ ksi}$$

$P = \pm\ 2.52$ kip

$M = \pm\ 2.333$ in-kip

$F_z = \pm\ 1.5$ kip

$M = 2.333 + 2.52\ (23.87) = 62.49$ in-kip

$$\sigma_{BEND} = \frac{62.49}{21.77} = 2.871 \text{ ksi}$$

$$\sigma_{AX} = \frac{1.5}{10.166} = 0.148 \text{ ksi}$$

Total Stress

$\sigma_{BEND} = 5{,}229$ psi | $= \pm\ 9{,}980$ psi

$\sigma_{AX} = 416$ psi | $= \pm\ 158$ psi

30.3.3.3 Pressure Stress. At Section F and G, the thicknesses are 0.576 inch and 0.4885 inch compared to thicknesses of 0.5855 inch and 0.50 inch, respectively, in the previous nominal calculations. This thickness disparity is expected to affect only the primary stress component, leaving the secondary and peak stresses the same. Therefore, the stresses in these sections are equal to the stresses obtained in the previous nominal calculations, plus a correction stress. This correction stress is calculated as follows:

Section F

Pressure = 1111 psi

Thickness = 0.576 in; 0.5855 in

Diameter = 9.679 in; 9.669 in

Hoop	Axial
$\sigma_\theta = \frac{PD}{2t}$	$\sigma_\phi = \frac{PD}{4t}$

$\Delta\sigma_{Hoop} = \Delta\sigma_\theta = 161$ psi

$\Delta\sigma_{Axial} = \Delta\sigma_\phi = 81$ psi

30.3.3.3 (Continued)

Section G

Pressure = 111 psi

Thickness = 0.4885 in; 0.500 in

Diameter = 8.413 in; 8.38 in

Hoop	Axial
$\sigma_\theta = \frac{PD}{2t}$	$\sigma_\phi = \frac{PD}{4t}$

$\Delta\sigma_{Hoop} = \Delta\sigma_\theta = 26$ psi

$\Delta\sigma_{Axial} = \Delta\sigma_\phi = 13$ psi

30.3.3.4 Total Primary Plus Secondary Stress Ranges. Calculations of P + Q stress intensity ranges at Sections F and G will be performed to validate the subsequent fatigue analysis. These stresses are calculated in the same manner as those in Paragraph 4.2.5.

30.3.3.4.1 Thermal Stress Ranges. The thermal stress ranges are identical to those found in the previous nominal calculations (refer to Page 110).

Section	P + Q (ksi) (Membrane Plus Bending)	P + Q (ksi) (Membrane Only)
F	28.78	3.71
G	34.86	17.98

30.3.3.4.2 Mechanical Load Stress Range

Section	P + Q (ksi) (Seismic Incl)	P + Q ((ksi) (Seismic Not Incl)
F	24.68	7.87
G	20.28	5.65

30.3.3.4.3 Pressure Load Stress Range. These stress ranges are exactly the same as those found in the previous nominal calculations (refer to Page 111), plus the added stress calculated earlier.

Section	P + Q (ksi)
F	8.84
G	7.68

30.3.3.4.4 Total P + Q Range. The total P + Q stress range is as follows:

Section	P + Q Range (ksi)	P + Q Range (ksi) No Thermal Bending
F	62.3	37.23
g	62.82	45.94

The allowable range is 3 S_m = 55.8 ksi. Both locations are acceptable with thermal bending removed.

30.3.4 Fatigue Analysis. This section provides all the detailed fatigue analysis required to show an acceptable design.

30.3.4.1 Stress Concentration Factors

Section F

The geometry of Section F is illustrated in Figure 30.3.4.1-1. To calculate the stress concentration factor, Reference 6.6 will be used. The concentration factors used prior, (refer to Page 124), are (inner) 1.59, and (Outer) 1.48. The deviaton affects the outer factor only.

Assume: $r = 0$, hence $K_o = 4.0$

Then, using Paragraph 4.7.2.4 of Reference 6.6,

$$\frac{(K' - 1)}{(K_o - 1)} = 1 - \frac{\beta}{90}$$

Solving for K', using $\beta = (90 - 29)° = 61°$

$$K' \text{ outer} = 1.97$$

Section G

The geometry of Section G is illustrated in Figure 30.3.4.1-2. To calculate the stress concentration factor, Reference 6.6 will be used. The concentration factors used prior (refer to Page 126) are (inner) 1.0, (outer) 1.80. The deviation affects the inner factor only.

Assume: $r = 0$, hence, $K_o = 4.0$

Then using Paragraph 4.7.2.4 of Reference 6.6,

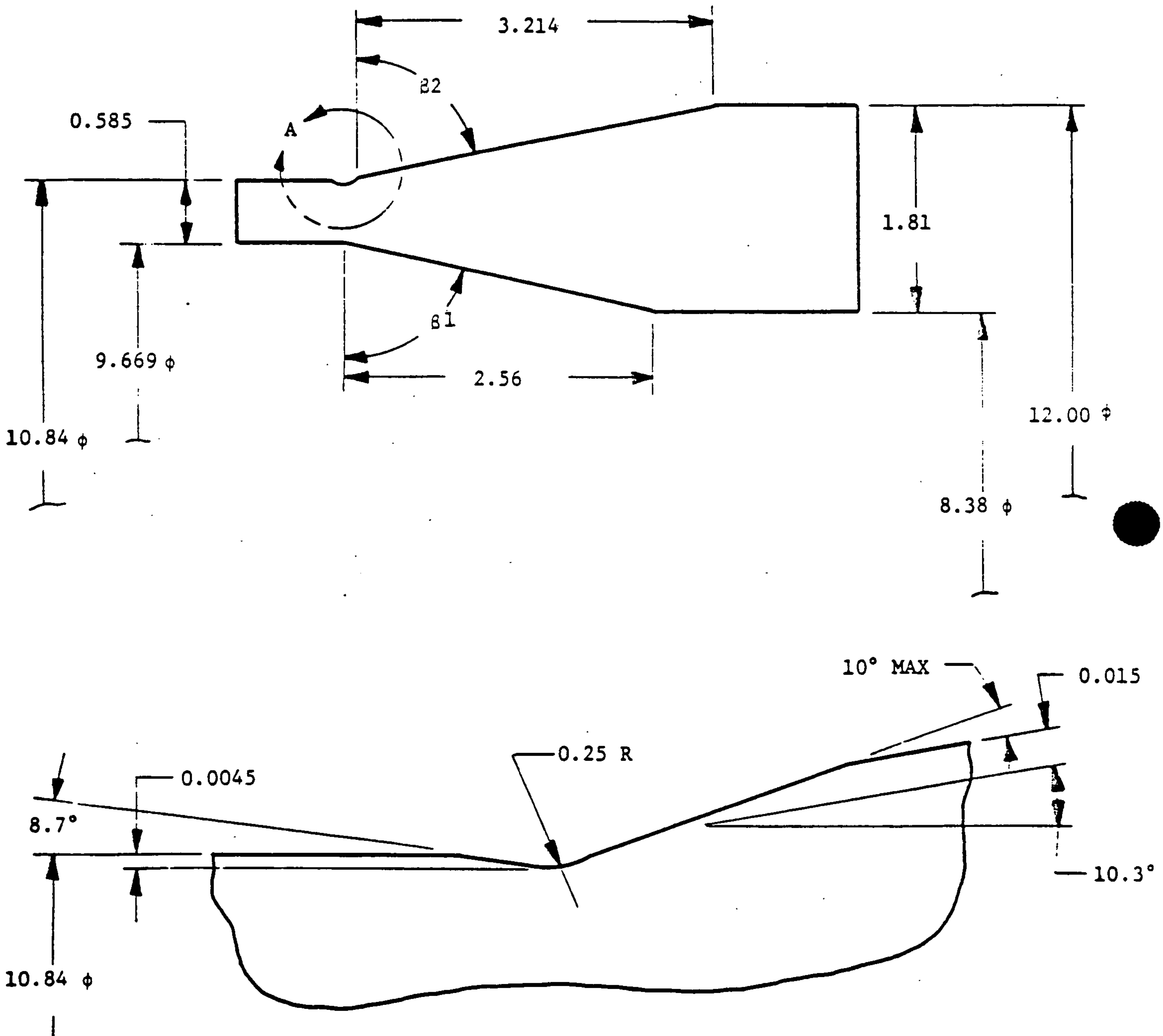
$$\frac{(K' - 1)}{(K_o - 1)} = 1 - \frac{\beta}{90}$$

Solving for K', using $\beta = (90 - 10)° = 80°$

$$K' \text{ inner} = 1.333$$

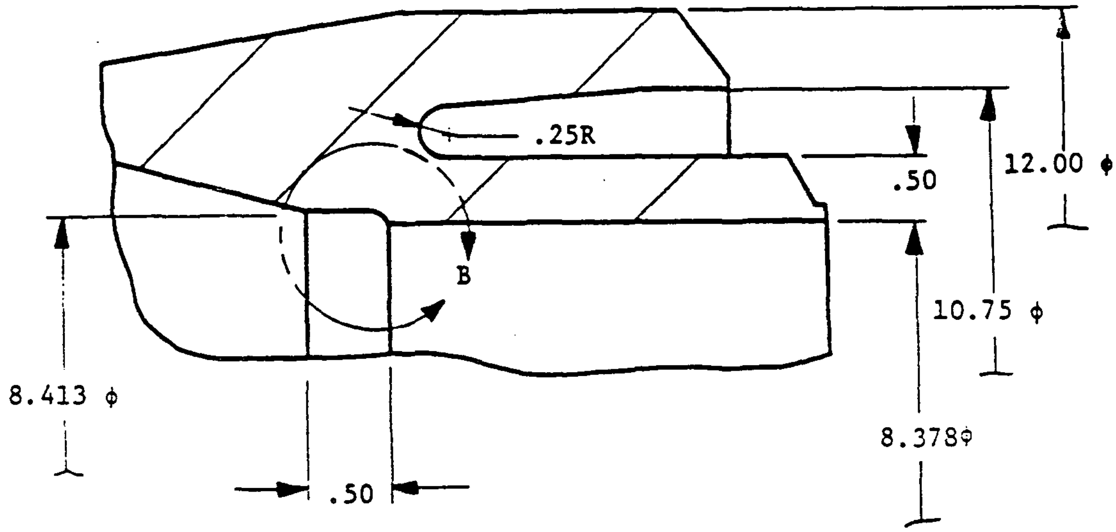
Since K' outer is larger than K' inner, K' outer will be used in the fatigue analysis.

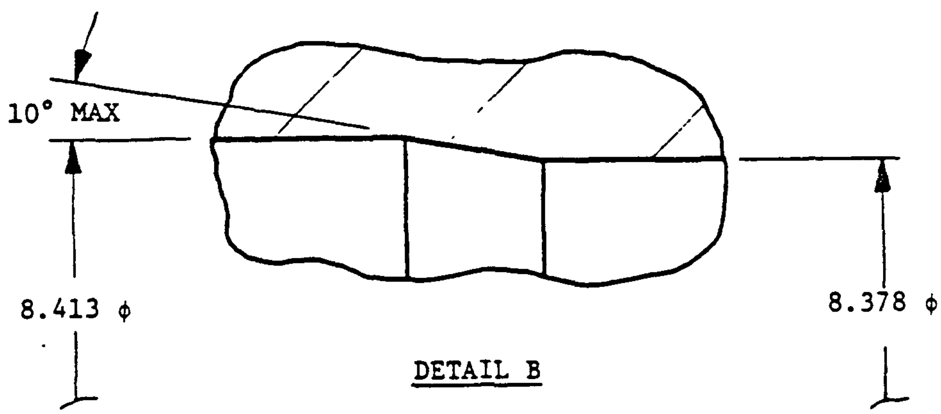
$$K' = 1.80$$



DETAIL A

FIGURE 30.3.4.1-1 SECTION F DEVIATION AFTER BLENDING





DETAIL B

FIGURE 30.3.4.1-2 SECTION G DEVIATION AFTER BLENDING

30.3.4.2 Alternating Stress Range. To calculate the altenating stress range, the following equation is needed:

$$S_{alt} = 1/2\ K_e\ (K_t\ S_N + F_1)$$

where:

$$K_e = \begin{cases} 1.0 \text{ for } S_N < 3S_m \\ 1 + \dfrac{(1-n)}{n(m-1)} \quad \dfrac{S_N}{3S_m} - 1 \text{ for } 3S_m < S_N < m3S_m \\ \dfrac{1}{n} \text{ for } S_N > m3S_m \end{cases}$$

For carbon steel $n = 0.2;\ m = 3.0$

K_t = stress concentration factor

S_N = P + Q stress intensity range

F_1 = peak stress

For Sections F and G, the peak stresses calculated in the previous nominal calculations are assumed to be identical. The deviations are not severe enough to significantly vary these stresses.

Location	Mechanical Range (Seismic)	Mechanical Range (No Seismic)	Thermal Range	Pressure Range	S_N (Seismic)	S_N (No Seismic)
F	24.68	7.87	28.78	8.84	62.30	45.49
G	20.28	5.65	34.86	7.68	62.82	48.19

(All stress in ksi)

30.4.3.2 (Continued)

Location	S_N (Seismic)	S_N (No Seismic)	K_t	F_1	K_e (Seismic)	S_{alt} (Seismic)	S_{alt} (No Seismic)
F	62.30	45.49	1.97	11.93	1.233	83.0	50.78
G	62.82	48.19	1.80	6.45	1.252	74.8	46.6

Using the total alternating stress range, the fatigue usage factors can be solved. From the design specification (Reference 6.1), there are 1,500 thermal cycles and it is assumed there are 10 seismic cycles. (Note: SA-350-LF2 has UTS < 80,000 psi.)

(Seismic)

Location	(ksi) S_{alt}	Elastic Modulus Factor	(ksi) S_A	Allowable Cycles	Usage Factor
F	83.0	1.103	91.55	750	0.0133
G	74.8	1.103	82.50	1000	0.010

(No Seismic)

Location	(ksi) S_{alt}	Elastic Modulus Factor	(ksi) S_A	Allowable Cycles	Usage Factor
F	50.78	1.103	56.01	3500	0.4257
G	46.6	1.103	51.40	3750	0.3973

Location	Total Usage Factor
F	0.439
G	0.407

For these sections (F and G), the high cycle and existing fatigue usage are negligible. Therefore, the above is the total fatigue usage.

86-020

EXHIBIT 9

REACTOR VESSEL RAPID CYCLING
(STRESS REPORT)

EIS IDENT: RV (RAPID CYC)

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION

REVISION STATUS SHEET

22A7227	
CONT ON SHEET 2	SH NO. 1

MNTS-...57
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DOCUMENT TITLE REACTOR VESSEL (RAPID CYCLING)

☒ SPECIFICATION ☐ DRAWING ☐ OTHER

TYPE STRESS REPORT

FMF MONTICELLO

MPL No. N/A

LEGEND OR DESCRIPTION OF GROUPS

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CHKD BY RE HAMILTON R.E. Hamilton OCT 30, 1980	ISSUED GA BAYLIS G. Baylis NOV 26 1980	CONT ON SHEET 2	SH NO. 1

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R

Certification of Stress Report

This certification for the Reactor Vessel (Rapid Cycling) Stress Report, and accompanying documents, constitute the basis for the Stress Report required by Paragraph NCA-3550 of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1977 Edition, with addenda to and including Summer 1978. I hereby certify that this stress report was prepared under my direct supervision and that I am a duly registered Professional Engineer under the laws of the state of Minnesota. I certify that, to the best of my knowledge and belief, the Stress Report for the Reactor Vessel (Rapid Cycling) is correct and complete and in compliance with the requirements of Article NB-3000 of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1977 Edition, with Addenda to and including Summer 1978.

Listed Documents

Type of Document	Title	Document Number	Revision Number
Design Specification	Reactor Vessel (Rapid Cycling)	22A7111	0

Certified By: James Edward Charnley P.E. Number 14372
Registered Professional Engineer
JAMES EDWARD CHARNLEY

State: Minnesota Date: 26 Nov 1980

1. SCOPE

1.1 This report documents a rapid cycling fatigue analysis of the feedwater nozzle replacement safe end and thermal sleeve assembly for the 'removable' type sparger at Monticello. The analysis was performed in accordance with the ASME Code, Section III (Reference 6.3). The detailed analysis is contained in Appendix 10 of this report.

2. SUMMARY AND CONCLUSIONS

2.1 The calculations presented in this stress report for the feedwater nozzle replacement safe end assembly show that, with no leakage, the fatigue usage factor due to rapid cycling is very low (less than 0.0001 during 40 years).

3. DESIGN

3.1 The feedwater nozzle replacement safe end and thermal sleeve assembly shown in Figure 1 are designed and analyzed in accordance with the documents referenced in Paragraphs 6.1 and 6.2.

4. ANALYSIS

4.1 Thermal Stress Cycles. There are two types of thermal cycles defined in the specifications referenced in Paragraphs 6.1 and 6.2: (1) system cycles and (2) rapid cycles. System cycles are the result of operational transients such as startup, initiation of feedwater flow, scrams, etc, being imposed on the nozzle. Rapid temperature cycling results in the unstable turbulent mixing of hot and cold water around the feedwater nozzle at steady state operating conditions. Since the system cycle transient stresses cause the maximum thermal stresses that can be produced, the rapid cycle stresses are not linearly additive to the maximum system cycle stresses, ie, the stresses and fatigue damage due to system cycles and rapid cycling may be calculated independently of each other and the usage factors may be added.

4.2 System Cycle Fatigue Analysis. The system cycles defined in Reference 4.2 will be analyzed elsewhere.

4.3 Rapid Cycle Fatigue Analysis. The equations and procedures for determining rapid cycle fatigue, as defined in Reference 6.1 were programmed into a timeshare computer code. The details of this code are presented in Appendix 10. In this code, the usage factor is calculated for a design life of 40 years, as specified in Reference 6.1.

5. RESULTS

5.1 Based on the data obtained from Reference 6.1, the fatigue usage factor caused by rapid cycling in the nozzle, safe end and thermal sleeve was calculated, as shown in detail in Appendix 10. The assumption that no feedwater, or an insignificant amount, leaks through the interference fit between the sparger tee and the replacement thermal sleeve (inner thermal sleeve, Figure 1) was made. For a design life of 40 years, the rapid cycling usage factor will be less than 0.0001 for all locations.

6. REFERENCES

6.1 General Electric Company, Reactor Vessel (Rapid Cycling), Design Specification 22A7111, Rev. 0.

6.2 Reactor Vessel (System Cycling), Design Specification 22A6996, Rev. 0.

6.3 ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1977 Edition with Addenda through 1978.

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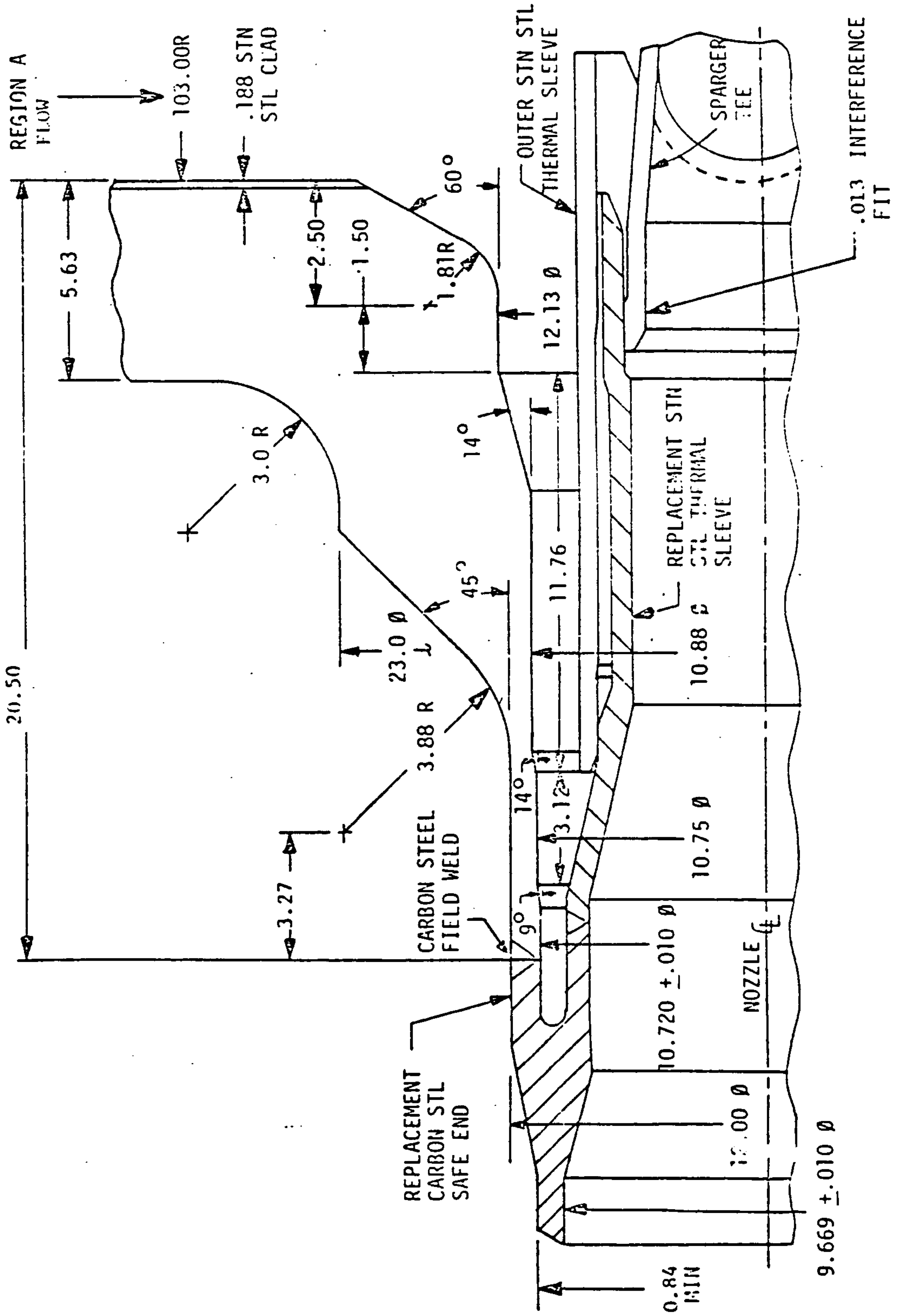

NOTE: NOZZLE DIMENSIONS ARE REFERENCE DIMENSIONS

FIGURE 1 EXISTING FEEDWATER NOZZLE AND REPLACEMENT SAFE END ASSEMBLY

APPENDIX 10 RAPID CYCLING FATIGUE CALCULATION

10.1 Introduction

10.1.1 The purpose of this analysis is to determine the rapid thermal cycling effects on the feedwater nozzle and safe end for the design life of the system.

10.1.2 Rapid temperature cycling (on the order of 0.1 to 1.0 Hz) occurs as a result of cold feedwater being injected into a hot reactor. The most dominant cause of this cycling in the nozzle bore and on the blend radius is turbulent mixing of leakage flow with Region A fluid (see Figure 10.1). Rapid cycling is caused in the absence of leakage flow by turbulent Region A fluid causing the thermal boundary layer around the cold thermal sleeve to be broken up and swept against the nozzle. Incompletely mixed sparger discharge flow and Region A fluid that is carried back to the nozzle also causes some rapid cycling.

10.2 Procedure

10.2.1 The procedure for determining rapid cycle fatigue is given in Reference 6.1. A computer program was developed, based on this procedure. The following includes a detailed description of the method and a listing of the program used to calculate the effect of rapid cycling.

10.3 Fatigue Evaluation

10.3.1 Stress Calculation. The following information established the condition for rapid cycling:

a. Amplitude and frequency from Table 10-1.

b. Feedwater flow, temperature, and time data from Table 10-3.

For each of the 26 data points in Table 10-3, there are 11 data points in Table 10-1.

10.3.1 (Continued)

The metal surface temperature range is calculated to determine the alternating stress produced by rapid cycling. Metal surface temperature range is calculated according to the formula (given in the design specification, Reference 4.1):

$$\Delta T_{p-p} = \bar{A} \; [(C)(T_A - T_{FW})]$$

where

ΔT_{p-p} = Metal surface peak to peak temperature range, °F

$\bar{A}$ = amplitude coefficient for a given frequency of cycling, from Table 10-1

C = coefficient from Table 10-2

T_{FW} = feedwater temperature from Table 10-3

T_A = Region A reactor water temperature from Table 10-3

TABLE 10-1 AMPLITUDE/FREQUENCY DATA FOR RAPID CYCLING (See Figure 10.1)

Locations a to ι

Index I	Amplitude A	Frequency Cycles/Hr
1	1.00	15
2	0.98	15
3	0.955	15
4	0.91	30
5	0.84	75
6	0.75	120
7	0.65	150
8	0.55	180
9	0.45	450
10	0.35	1200
11	0.20	7500

TABLE 10-2 COEFFICIENT C FOR NOZZLE SURFACE DOWNSTREAM OF THERMAL SLEEVE JUNCTION (See Figure 10.1 and Notes 1 and 2)

Location	C
a	0.10
b	0.09
c	0.10
d	0.10
e	0.10
f	0.12

NOTES:

1. Interpolate linearly between defined points.

2. The coefficients are zero for locations not specified.

TABLE 10-3 FLOW, TEMPERATURE AND TIME DATA FOR RAPID CYCLING

Index J	Feedwater Flow % Rated	Feedwater Temperature °F	Region A Temperature °F	Time %	Hours Per Year
1	100	375	546	67.87	5945
2	100	360	546	7.37	646
3	82	345	543	14.75	1292
4	46	300	538	0.98	86
5	36	280	537	0.45	39
6	20	260	540	0.36	31.5
7	6	225	540	0.32	28
8	6	185	540	0.08	7
9	2.5	185	540	0.12	10.5
10	2.5	240	525	0.16	14
11	2.5	280	480	0.52	45.5
12	2.5	265	450	0.12	10.5
13	2.5	210	420	0.16	14
14	2.5	185	365	0.56	49
15	2.5	185	470	0.04	3.5
16	2.5	125	450	0.76	66.5
17	2.5	80	215	0.32	28
18	2.5	80	170	0.36	31.5
19	0	300	340	0.49	43
20	1	350	360	0.005	0.4
21	2	190	350	0.013	1.1
22	2	125	340	0.009	0.8
23	2	70	330	0.005	0.4
24	2	190	400	0.013	1.1
25	3	200	340	0.002	0.2
26	0	70	70	4.17	365.5

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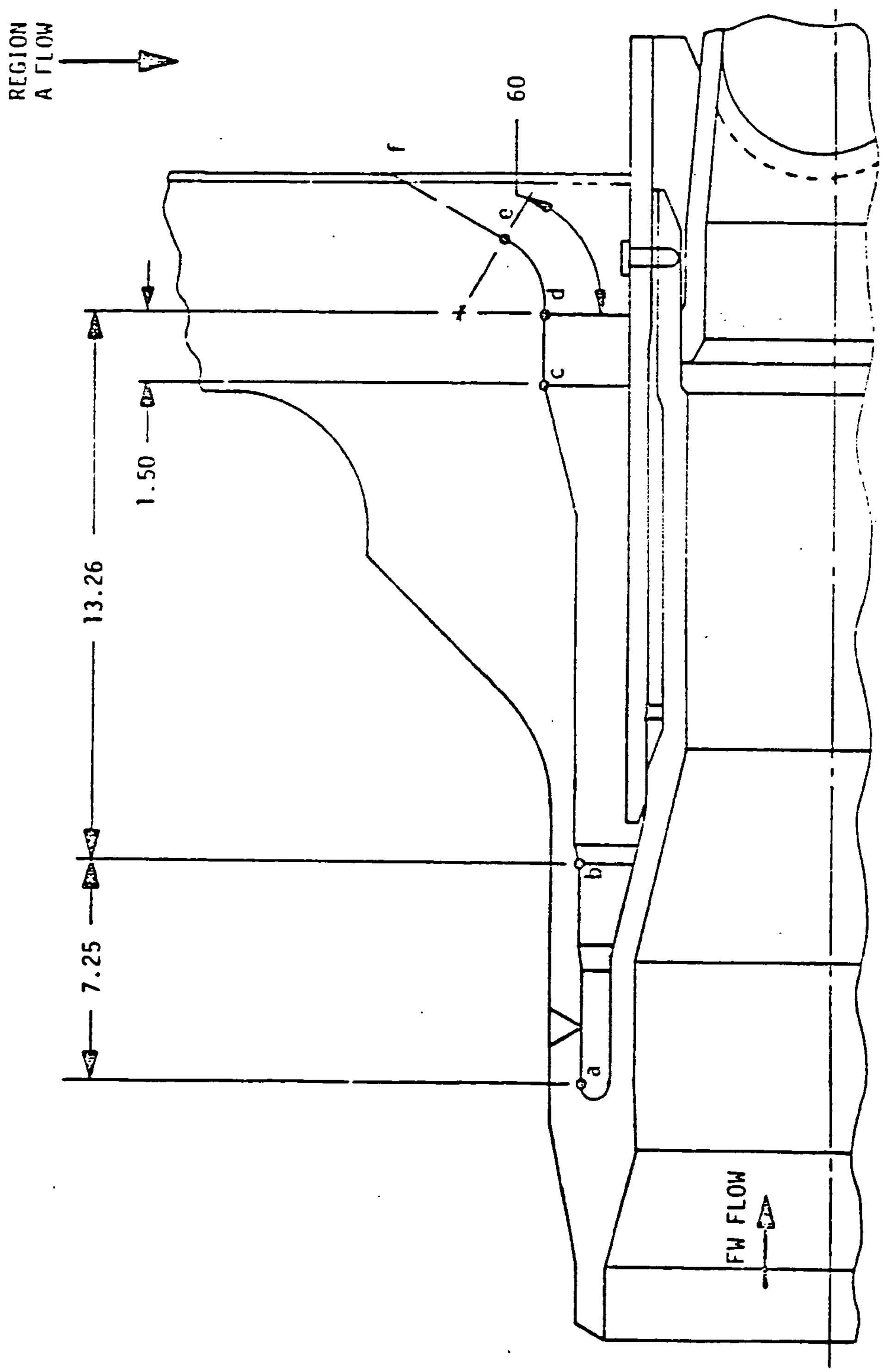

FIGURE 10.1 HEAT TRANSFER AND FEEDWATER FLOW LOCATIONS

Alternating stress is calculated according to the formula

$$\sigma_{alt} = \frac{E\alpha\Delta T_{p-p}}{2(1-\nu)}$$

where

E = Young's Modulus = 30.0×10^6 } From Reference 6.1

ν = Poisson's Ratio 0.3

α = Instantaneous coefficient of thermal expansion interpolated between points given in Table I-5.0 of ASME Code, Section III, Subsection AN where α is evaluated at a temperature of

$$T = T_A - 0.5\ (\Delta T_{p-p})$$

10.3.2 Usage Factor. The number of cycles and the allowable number of cycles are calculated to determine the rapid cycling usage factor.

The number of cycles allowed is determined from the ASME Code (Figure I-9.1) (Reference 6.3) for a given alternating stress, σ_{alt}.

The number of cycles accumulated from rapid thermal cycling is calculated according to the equation

$$\text{Cycles} = t \bullet f \bullet D \bullet L$$

where

Cycles = cycles induced by rapid cycling

f = frequency of cycling from Table 10-1 in cycles/hr

t = time at each feedwater/flow/temperature combination from Table 10-3 in %

D = design life of nozzle and safe end = 40 years (from the design specification)

L = 8,760 hrs/yr

The usage factor is given by the following equation:

$$U = \sum_{\substack{i=1 \\ j=1}}^{\substack{26 \\ 11}} U_{ij}$$

where

U = usage factor due to rapid cycling

U_{ij} = usage factor due to i^{th} amplitude and frequency (Table 10-1) and for the j^{th} flow, temperature and time (Table 10-3)

10.3.3 Computer Program. A computer program based on the preceeding procedure was developed. Table 10-4 is a listing of the program.

10.3.4 Output. The tabulated results of the computer program, Table 10-4, are listed in Table 10-5.

TABLE 10-4

```
0020C MAMFWS
0030C
0040C  THIS PROGRAM IS USED TO CALCULATE RAPID CYCLING ON THE FEEDWATER (FW)
0050C  NOZZLE AND SAFE END BY DETERMINING THE TEMPERATURE GRADIENTS (DELTA T)
0060C  AT 6 POINTS ON THE SAFE END. THE DELTA T'S ARE CALCULATED AS A
0070C  FUNCTION OF FW TEMP,FW FLOW,FREQUENCY OF THE RAPID CYCLING DUE TO
0080C  TURBULENT FLOW, ETC, AND TIME AT TEMP. AND FLOW OF THE SAFE END.
0090C  THE DELTA T'S ARE THEN RELATED TO COMPRESSIVE STRESS IN ORDER TO
0100C  DETERMINE THE NUMBER OF CYCLES ALLOWABLE FROM THE ASME B&PV CODE.
0110C
0120   REAL RATFWF(26), TEMPFW(26), FWTIME(26), AMP(11)  FREQ(11)
0130   REAL ALPHA(11), ALPHAT(11), TEMP(6,26), TEMPDC(26)
0140   REAL DELTAT(6,26), STRESS(6,26), ALPHINT(6), C3(6,26)
0150C
0160C  RATED FW FLOW (RATFWF), FW TEMPERATURE (TEMPFW), AMPLITUDE OF THE
0170C  RAPID CYCLING (AMP) AND FREQUENCY OF THE RAPID CYCLING (FREQ) ARE
0180C  GIVEN BY "DESIGN SPECIFICATION FOR FEEDWATER NOZZLE AND SAFE END
0190C  REPAIR". THERMAL EXPANSION (ALPHA) , MODULUS OF ELASTICITY
0200C  (EMOD), AND POISSON'S RATIO (POISSON) ARE GIVEN BY ASME B&PV
0210C  SECTION III, TABLES I-5.0 AND I-6.0.
0220C
0230   DATA DLIFE/40.0/
0240   DATA RATFWF/1.000,1.000,.82,.46,.36,.20,.06,.06,.025,.025,.025,
0250&              .025,.025,.025,.025,.025,.025,.025,0.0,.01,.02,
0260&              .02,.02,.02,.03,0.0/
0270   DATA TEMPFW/375.,360.,345.,300.,280.,260.,225.,185.,185.,240.,
0280&              280.,265.,210.,185.,185.,125.,80.,80.,300.,350.,
0290&              190.,125.,70.,190.,200.,70./
0300   DATA FWTIME/.6787,.0737,.1475,.0098,.0045,.0026,.0032,.0008,
0310&              .0012,.0016,.0052,.0012,.0016,.0056,.0004,.0076,.0032,
0320&              .0036,.0049,.00005,.00013,.00009,.00005,.00013,.00002,
0330&              .0417/
0340   DATA AMP/1.0,0.98,0.955,0.91,0.84,0.75,0.65,0.55,0.45,0.35,0.20/
0350   DATA FREQ/15.,15.,15.,30.,75.,120.,150.,180.,450.,1200.,7500./
0360   DATA TEMPDC/546.,546.,543.,538.,537.,540.,540.,540.,540.,525.,
0370&              480.,450.,420.,365.,470.,450.,215.,170.,340.,300.,
0380&              350.,340.,330.,400.,340.,70./
0390   DATA POISSON/0.3/
0400   DATA ALPHA/6.07,6.20,6.44,6.67,6.89,7.10,7.33,7.54,7.76,7.96,8.16/
0410   DATA ALPHAT/70.,100.,150.,200.,250.,300.,350.,400.,450.,500.,550./
0420C
0430C  CALCULATE THE NUMBER OF CYCLES FOR EACH DELTA T AS A FUNCTION
0440C  OF RATFWF AND TEMPFW.
0450   PRINT: " "
0460   PRINT: "MONTICELLO RAPID CYCLE FATIGUE ANALYSIS"
0470   PRINT:"    VALUES FROM NEW ECKERT FLOW MAP "
0480   PRINT: " DESIGN LIFE = ",DLIFE
0490   PRINT:" "
0500   PRINT:" "
0510C
```

```
0520C   CALCULATE FOR EACH OF 6 POINTS ON THE THERMAL SLEEVE THE
0530C   APPROPRIATE DELTA T WHERE K=1 FOR POINT A; K=2 FOR POINT B,
0540C   K=3 FOR POINT C; K=4 FOR POINT D; K=5 FOR POINT E; AND K=6 FOR
0550C   POINT F.
0560C
0570    DO 1000 K=1,6
0580    SUSGFA C= 0.0
0590    DO 500 J=1,26
0600    C3(1,J) = 0.10
0610    C3(2,J) = 0.09
0620    C3(3,J) = 0.10
0630    C3(4,J) = 0.10
0640    C3(5,J) = 0.10
0650    C3(6,J) = 0.12
0660    ZUSGFA C= 0.0
0670C
0680    DO 100 I = 1,11
0690    DELTAT(K,J) = AMP(I) * C3(K,J) * (TEMPDC(J) - TEMPFW(J))
0700    TEMP(K,J) = TEMPDC(J) - 0.5 * DELTAT(K,J)
0710C
0720C    LINEARLY INTERPOLATE TO DETERMINE ALPHA AS A FUNCTION OF TEMPERATURE
0730C   WHERE TEMPERATURE IS GIVEN  FROM THE SPE CAS
0740C                  T= TDC-0.5*DELTA T
0750C
0770    DO 10 L=1,11
0780    IF (TEMP(K,J) .LT. ALPHAT(L) .OR. TEMP(K,J) .GT. ALPHAT(L+1))
0790&    GO TO 10
0800   SLOPE = (ALPHAT(L+1) - ALPHAT(L))/(ALPHA(L+1) - ALPHA(L))
0810    ALPHINT(K) = ALPHA(L) + (TEMP(K,J) - ALPHAT(L))/SLOPE
0830 10  CONTINUE
0850C
0860    CYCLES = FWTIME(J) * FREQ(I) * 8760. * DLIFE
0870    STRESS(K,J) = DELTAT(K,J) * ALPHINT(K) *30.0/(2.0*(1.0-POISSON))
0880    IF (STRESS(K,J) .GT. 5.8E5) CYALLOW = (STRESS(K,J)/1.4E6)**(-2.2363)
0890    IF(STRESS(K,J) .LE. 5.8E5 .AND. STRESS(K,J) .GT. 2.0E5)
0900&          CYALLOW = (STRESS(K,J)/1682000.)**(-2.16264)
0910    IF(STRESS(K,J) .LE. 2.0E5 .AND. STRESS(K,J) .GT. 8.4E4)
0920&          CYALLOW = (STRESS(K,J)/1133787.)**(-2.05428)
0930    IF(STRESS(K,J) .LE. 8.4E4 .AND. STRESS(K,J) .GT. 3.75E4)
0940&          CYALLOW = (STRESS(K,J) /944112.)**(-2.65512)
0950    IF(STRESS(K,J) .LE. 3.75E4 .AND. STRESS(K,J) .GT. 2.0E4)
0960&          CYALLOW = (STRESS(K,J)/463486.)**(-3.66209)
0970    IF(STRESS(K,J) .LE. 2.0E4 .AND. STRESS(K,J) .GT. 1.24E4)
0980&          CYALLOW = (STRESS(K,J)/218309.)**(-4.81676)
0990    IF(STRESS(K,J) .LE. 1.24E4 .AND. STRESS(K,J) .GT. 9.4E3)
1000&          CYALLOW = (STRESS(K,J)/65340.8)**(-8.312978)
1010    IF(STRESS(K,J) .LE. 9.4E3 .AND. STRESS(K,J) .GT. 7.7E3)
1020&          CYALLOW = (STRESS(K,J)/37932.9)**(-11.54240)
1030    IF(STRESS(K,J) .LE. 7.7E3 .AND. STRESS(K,J) .GT. 7.0E3)
1040&          CYALLOW = (STRESS(K,J)/16505.63)**(-24.15880)
1050    IF(STRESS(K,J) .LE. 7.0E3) GO TO 100
1060    USGFA C= CYCLES/CYALLOW
```

```
     ZUSGFA C= ZUSGFA C+ USGFAC
     SUSGFA C= SUSGFA C+ USGFAC
100 CONTINUE
     PRINT:"  AT ZONE ",J
     PRINT:" STRESS (SIGMA ALT)  = ",STRESS(K,J)/0.20
     PRINT:"    SUM OF USAGE FACTORS =",ZUSGFAC
     PRINT:" "
500 CONTINUE
     PRINT:"         AT POINT ",K
     PRINT:"         SUM OF USAGE FACTORS = ",SUSGFAC
     PRINT:" "
1000 CONTINUE
     STOP
     END
$         EXECUTE
$         ENDJOB
```

TABLE 10-5 TABULATED RESULTS OF COMPUTER PROGRAM

Usage Factors

Zone/Point	1	2	3	4	5	6
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	.25 E-4
9	0	0	0	0	0	.38 E-4
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	0	0	0	0	0	0
Sum of Usage Factors	0	0	0	0	0	.63 E-4

Total = 0.63×10^{-4}