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ENGINEERING

CENC 1197

VOLUME II

LMFBR
SODIUM HEATED
STEAM GENERATOR
—TEST MODEL—

AEC CONTRACT AT(11-1)-3031

FEBRUARY 1973

MASTER

CE COMBUSTION DIVISION

COMBUSTION ENGINEERING, INC.

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LMFBR STEAM GENERATOR

30 MWt SODIUM TEST

MODEL

EVAPORATOR AND SUPERHEATER MODULES

I.M.Q. PLAN

APPENDIX D.1

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COMBUSTION ENGINEERING, INC.
CHATTANOOGA, DIVISION
CHATTANOOGA, TENNESSEE

LMFBR STEAM GENERATOR
30 MWt SODIUM TEST MODEL
EVAPORATOR AND SUPER/HEATER

INTEGRATED MANUFACTURING - QUALITY PLAN

CONTRACT 7670

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DATE: February 1, 1973

REVISION: 0

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SYMBOLS AND DEFINITIONS

#	Inspection Point
I.D.	Inside Diameter
O.D.	Outside Diameter
M.T.	Magnetic Particle Test
P.T.	Dye Penetrant Test
R.T.	Radiographic Test
W.I.F.	Weld Inspection Form

STANDARD M.T. REPAIR CYCLE

Remove defects.

M.T. grindouts.

#

Weld repairs.

WIF

Interstage stress relieve.

Review charts.

#

Grind repairs.

M.T. repairs.

#

STANDARD R.T. REPAIR CYCLE

Remove Defects.

M.T. Grindouts.

#

Weld repairs.

WIF

Interstage stress relieve.

Review charts.

#

Grind repairs.

M.T. repairs.

#

X-ray repairs.

Review film.

#

TOOLING REQUIREMENTS

1. Egg Crate Assembly Fixture
2. Egg Crate Stress Relief Fixture
3. Baffle Flange Drill Jig
4. Baffle and Tube Bundle Up-Ending and Vertical Support
5. Tube Sheet Center Plate Handling Fixture
6. Tube Support For Up-Ending
7. Primary Shell Rounding Rings
8. Tube Sheet Assembly Lifting and Turning Fixture
9. Sodium Shell Rounding Rings
10. Sodium Shell 3-D Template
11. Cone Extension Rounding Ring
12. Support Base Drill Template
13. Support Skirt 3-D Template
14. Key Ring Grinding Templates
15. Sodium Shell-Lower Rounding Rings
16. Top Cover Plate Lifting and Turning Fixture
17. Flange Lifting and Turning Fixture
18. Nozzle Cladding Fixture
19. Sodium Shell Flange Lifting and Turning
20. Nozzle Handling Rig
21. Middle Shell Rounding Ring
22. Shell Key Grinding Templates
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24. Nozzle Liner Expansion Spool and Collar
25. Shell Liner Rounding Ring and Handling Fixture

Tooling Requirements (Continued)

26. Nozzle Liner Rounding Ring and Handling Fixture
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40. Baffle Fit-up Fixture
41. Tube Locking Nut Drive Equipment
42. Button Installation Equipment
43. Up-Ending and Assembly for Hydro
44. Gun Drills and Bushings
45. Special Cutting Tools
46. Omega Seal Holding Fixture

TUBE SHEET RING FORGING

Material release

#

Machine prep for tube sheet.

Inspect machining.

#

Layout hydrogen probe areas.

Inspect layout.

#

Machine pilot holes and preps for hydrogen probe and gas vents.

Inspect machining.

#

M.T. weld preps.

#

TUBE SHEET FORGING

Material release.

#

Machine weld prep for ring.

Inspect machining.

#

M.T. weld prep.

#

TUBE SHEET ASSEMBLY

Fit-up tube sheet to ring forging.

Inspect fit-up.

#

Weld tie straps.

Weld seam.

WIF

Interstage stress relieve.

Review furnace charts.

#

Remove tie straps.

Machine for cladding, remove stock from faces.

Inspect machining.

#

X-ray weld seam.

Review film.

#

M.T. weld seam and machined surfaces.

#

Chip indications.

Grind indications.

M.T. grindouts.

#

Weld repair tube sheet to ring

WIF

Seam and clad "J" preps

Interstage H.T.

Tube Sheet Assembly (Continued)

Review furnace charts.	#
Grind repairs and "J" preps.	
M.T. girth seam repairs.	#
R.T. girth seam repairs.	
Review film.	#
P.T. "J" preps	#
Remove "J" prep indications.	
P.T. grindouts "J" preps.	#
Weld repair "J" preps.	# WIF
Grind repairs.	
P.T. repairs.	#
Clad tube sheet manually and area for Omega seal.	# WIF
Interstage stress relieve.	
Review furnace charts.	#
Machine clad VBM.	
Inspect machining.	#
P.T. clad.	#
Remove indications.	

Tube Sheet Assembly (Continued)

P.T. grindouts.	#
Weld repair clad.	# WIF
Inspect prior to final stress relieve.	#
Final stress relieve.	
Review furnace charts.	#
Grind repairs.	
P.T. clad.	#
U.T. clad surface.	#
Layout stud holes.	
Inspect layout.	#
Rough drill stud holes.	
Inspect machining.	#
HBM mach. tube holes, tube weld preps.	
Inspect machining.	#
P.T. tube weld preps.	#
Remove indications.	
Weld repair tube weld preps.	# WIF

Tube Sheet Assembly (Continued)

Final stress relieve.

Review furnace charts.

#

Machine tube sheet repairs.

Inspect machining.

#

P.T. clad.

#

Machine bolting circle on tube sheet face.

Inspect machining.

#

Clean tube sheet assembly.

Fit-up Omega Seal.

Inspect fit-up.

#

Weld Omega Seal.

#

P.T. each seal weld layer.

#

Grind seal weld.

P.T. seal weld finish surface.

#

P.T. repair cycle.

#

TUBE SHEET TO TUBE BUNDLE

Set-up for welding tubes to tube sheet.

Inspect set-up and cleanliness of area and component. #

Fit-up first row of tubes (11) tubes.

Inspect fit-up. #

Weld tubes to tubesheet. # WIF

Interstage stress relieve.

Review charts. #

Prepare seams for NDT.

X-ray tube to tube sheet welds.

Review film. #

P.T. I.D. and O.D. of seams. #

Machine I.D. for repair of seams.

Inspect machining. #

Re-weld seam. # WIF

Interstage stress relieve.

Review charts. #

Ream I.D. of seam for NDT.

P.T. seams I.D. and O.D. #

Tube Sheet to Tube Bundle (Continued)

P.T. seams I.D. and O.D.	#
X-ray complete weld.	
Review film.	#
Helium leak test tube welds.	#
Fit-up 2 rows of tubes (20) tubes.	
Inspect fit-up.	#
Weld tubes to tube sheet.	# WIF
Interstage stress relieve.	
Review charts.	#
Prepare seams for NDT.	
Inspect.	
X-ray tube to tube sheet.	
Review film.	#
P.T. I.D. and O.D. of seams.	#
Machine I.D. for repair of seams.	
Inspect machining.	#
Re-weld seam.	# WIF
Interstage stress relieve.	

Tube Sheet to Tube Assembly (Continued)

Review charts. #

Ream I.D. of seams for NDT.

P.T. seams I.D. and O.D. #

X-ray welds.

Review film.

Helium leak test tube welds. #

Fit-up (2) rows of tubes (18) tubes.

Inspect fit-up. #

Weld tubes to tube sheet. # WIF

Interstage stress relieve.

Review charts. #

Machine I.D. of seam for NDT.

Inspect. #

X-ray tube to tube sheet welds.

Review film. #

P.T. I.D. and O.D. of seams. #

Machine I.D. for repair of seams.

Inspect machining. #

Tube Sheet to Tube Assembly (Continued)

Re-weld seams. # WIF

Interstage stress relieve.

Review charts. #

Ream I.D. of seams for NDT.

P.T. seams I.D. and O.D. #

X-ray welds.

Review film. #

Helium leak test tube welds. #

Fit-up (2) rows of tubes (16) tubes.

Inspect fit-up. #

Weld tubes to tube sheet. # WIF

Interstage stress relieve.

Review charts. #

Machine I.D. of seams for NDT.

Inspect. #

X-ray tube to tube sheet welds.

Review film. #

P.T. I.D. and O.D. of seams. #

Tube Sheet to Tube Assembly (Continued)

Machine I.D. for repair of seams.

Inspect machining.

#

Re-weld seams.

WIF

Interstage stress relieve.

Review charts.

#

Ream I.D. of seams for NDT.

P.T. seams I.D. and O.D.

#

X-ray welds.

Review film.

#

Helium leak test tube welds.

#

Fit-up (2) rows of tubes (14) tubes.

Inspect fit-up.

#

Weld tubes to tube sheet.

WIF

Interstage stress relieve.

Review charts.

#

Machine I.D. of seam for NDT.

Inspect.

#

X-ray tube to tube sheet welds.

Tube Sheet to Tube Assembly (Continued)

Review film.	#
P.T. I.D. and O.D. of seams.	#
Machine I.D. for repair of seams.	
Inspect machining.	#
Re-weld seams.	# WIF
Interstage stress relieve.	
Review charts.	#
Ream I.D. of seams for NDT.	
P.T. seams I.D. and O.D.	#
X-ray welds.	
Review film.	#
Helium leak test tube welds.	#
Fit-up last (2) rows of tubes 12 tubes.	
Inspect fit-up.	#
Weld tubes to tube sheet.	# WIF
Interstage stress relieve.	
Review charts.	#
Machine I.D. of seam for NDT.	

Tube Sheet to Tube Assembly (Continued)

Inspect.	#
X-ray tube to tube sheet welds.	.
Review film.	#
P.T. I.D. and O.D. of seams.	#
Machine I.D. for repair of seams.	
Inspect machining.	#
Re-weld seams.	# WIF
Interstage stress relieve.	
Review charts.	#
Ream I.D. of seams for NDT.	,
P.T. seams I.D. and O.D.	#
X-ray welds.	
Review film.	#
Helium leak test tube welds.	#
Final stress relieve tube welds.	
Review charts.	#

TUBE SHEET AND BAFFLE ASSEMBLY

Inspect tube sheet and tube bundle for cleanliness.

#

Attach tube sheet to baffle.

Inspect fit-up.

#

Seal openings to protect tube bundle.

HBM final machine stud holes, mating surfaces, seal, final stud holes, gas vents, and keyways.

Inspect layout.

#

Inspect machining.

#

Clean assembly.

Inspect cleanliness.

#

Set-up for attaching upper shell assembly.

TUBE SHEET AND BUNDLE ASSEMBLY TO UPPER SHELL ASSEMBLY

Fit-up upper shell to tube sheet assembly.

Inspect fit-up. #

Weld tie straps.

Weld girth seam. # WIF

Back groove seam and remove straps.

Grind back groove.

M.T. backgroove and strap areas. #

Weld backgroove. # WIF

Inspect prior to final stress relieve. #

Set-up for local stress relieve.

Final stress relieve.

Review charts. #

Remove local H.T. equipment.

Grind girth seam I.D. and O.D.

X-ray girth seam.

Review film. #

M.T. girth seam. #

Chip indication.

Tube Sheet and Bundle Assembly to Upper Shell Assembly (Continued)

Grind indications.

M.T. grindouts. #

Weld repair. # WIF

Set-up for local H.T.

Final stress relieve repairs.

Review charts. #

Remove local H.T. equipment.

Grind repairs.

X-ray repairs.

Review film. #

M.T. repairs. #

Clean assembly.

Set-up for hydro of stm. side.

Hydro stm. side.

Inspect . #

Drain and dry.

Helium leak test (must be approved by customer or performed before hydro.)

Tube Sheet and Bundle Assembly to Upper Shell Assembly (Continued)

Inspect. #

Fit-up gas vents and hydrogen probe nozzle.

Inspect fit-up. #

Weld. # WIF

Grind.

P.T. and repair.

VESSEL ASSEMBLY

Set-up and install tube bundle to sodium side shell.

Inspect.

#

Set-up for hydro of sodium side.

Hydro sodium side.

Inspect.

#

Drain and dry.

Helium leak test sodium side (approved by customer if hydro is performed.)

Inspect.

#

Prepare all seam for M.T.

M.T. accessible pressure boundary seams.

#

Fit-up stm. side nozzle sleeve and install tube plate and cylinder assembly bolt in place.

Inspect.

#

Inspect cleanliness, etc.

Install bayonet, insulator tube assemblies, and tube nuts.

Inspect.

#

Install remaining stm. side internals.

Inspect.

#

Vessel Assembly (Continued)

Set-up for removing hydro caps.

Remove hydro caps.

Machine nozzle weld preps.

Inspect machining and vessel cleanliness.

#

Fit-up nozzle shipping covers and close vessel.

Inspect.

#

Purge and pressurizer for shipping.

Leak test nozzle covers.

Inspect.

#

Paint.

Ship.

BAFFLE SHELL SEGMENTS (6)

Material release.	#
Layout flat plate for removing stock and identify.	
Inspect layout and identification.	#
Burn off excess stock.	
Layout for machining preps.	
Inspect layout.	#
Machine weld preps (6) plates.	
Inspect machining.	#
M.T. weld preps.	#
Sublet rolling.	
Receiving inspect.	#
Clean weld preps.	
Visual inspect preps per specifications.	#
Weld long seams (6) cylinders.	# WIF
Backgroove.	
Grind backgroove.	
M.T. backgroove.	#
Weld backgroove.	# WIF

Baffle Shell Segments (6) Continued

Interstage stress relieve.

Review charts and release.

#

Grind long seams.

X-ray long seams.

Review film and release.

#

M.T. long seams.

#

Remove defects.

M.T. grindouts.

#

Weld repair long seams.

WIF

Interstage stress relieve.

Review charts and release.

#

Grind repairs.

X-ray repairs.

Review film and release.

#

M.T. repairs.

#

Visual inspect welds per specification.

#

TOP BAFFLE SECTION

Round up top baffle section.

Install rounding rings.

Inspect roundness. #

Machine weld preps.

Inspect machining. #

Final stress relieve.

Review charts and release. #

M.T. weld prep. #

Visual inspect weld prep. #

Girth. #

Layout for cutting openings.

Inspect layout. #

Cut opening in top baffle section.

Grind to clean up openings.

Inspect finished openings. #

Clean top section and protect.

Inspect protection. #

BAFFLE SECTION SECOND FROM TOP

Round up baffle section.

Install rounding ring.

Inspect roundness.

#

Layout for cutting openings.

Inspect layout.

#

Cut openings.

Grind to clean up openings.

Inspect finish openings.

#

Install egg crate seal rings.

Inspect fit-up.

#

Weld seal rings.

WIF

Interstage stress relieve.

Review charts and release.

#

Clean seal ring welds.

M.T. welds.

#

Standard M.T. repair cycle.

Machine weld prep and seal rings.

Inspect machining.

#

Baffle Section Second from Top (Continued)

M.T. weld preps.	#
Clean 100%.	
Inspect cleanliness.	#
Fit-up egg crates.	
Inspect fit-up optically.	#
Weld egg crates to baffle.	# WIF
Inspect optically.	#
Final stress relieve.	
Review charts and release.	#
Inspect optically.	#
Visual inspect welds.	#
Clean and protect for assembly.	

Baffle Section Third from Top

Layout for cutting sections into (2) short cylinders.	
Inspect layout.	#
Out into (2) sections.	
Install rounding rings.	

Baffle Section Third from Top (Continued)

Machine preps on (1) end of each section.

Inspect machining. #

M.T. weld preps. #

Visual inspect preps. #

Fit-up keyway ring forging to cylinders.

Inspect fit-up. #

Weld girth seams. # WIF

Interstage stress relieve.

Review charts. #

Inspect straightness. #

Grind weld seams.

R.T. weld seams.

Review film and release. #

M.T. girth seams. #

Standard R.T. repair cycle.

Inspect straightness. #

Visual inspect seams.

Fit-up egg crate seal rings.

Baffle Section Third From Top (Continued)

Inspect fit-up.	#
Weld rings.	# WIF
Interstage stress relieve.	
Review charts.	#
Clean ring welds.	
M.T. welds.	#
Standard M.T. repair cycle.	
Visual inspect welds.	#
Machine weld preps and rings.	
Inspect machining.	#
Clean 100%.	
Fit-up egg crates.	
Optically align egg crates.	#
Weld egg crates to baffle.	# WIF
Optically inspect alignment.	#
Final stress relieve.	
Review charts.	#
Optically inspect.	#

Baffle Section Third From Top (Continued)

Visual inspect welds. #

Remove rounding ring from top end.

Install O.D. seal and seal ring over baffle.

Re-install rounding ring.

Inspect roundness. #

Optically check alignment. #

Clean assembly and protect.

Inspect cleanliness #

Baffle Section 4th & 5th from Top

Fitup rounding rings.

Inspect roundness.

Fitup egg crate seal rings.

Inspect fitup.

Weld seal rings. # WIF

Interstage stress relieve.

Review charts.

Grind to clean seal ring welds.

M.T. weld. #

Baffle Section 4th & 5th from Top (Continued)

Standard M.T. repair cycle.

Visual inspect welds. #

Machine weld preps and seal rings.

Inspect machining. #

M.T. preps. #

Visual inspect preps. #

Fitup egg crates.

Inspect optically. #

Weld egg crates. # WIF

Inspect alignment. #

Final stress relieve.

Review charts. #

Inspect alignment. #

Visual inspect welds. #

Clean assembly and protect.

Inspect cleanliness. #

Baffle Section 6th from Top

Fitup rounding rings.

Inspect roundness.

#

Machine prep for keyway ring.

Inspect machining.

#

M.T. weld prep.

#

Visual inspect prep.

#

Fitup keyway ring and egg crate seal rings.

Inspect fitup.

#

Weld girth seam and seal rings.

WIF

Interstage H.T.

Review charts and release.

#

Clean up welds.

R.T. girth seam.

Review charts and release.

#

M.T. seams.

#

Visual inspect welds.

Standard R.T. and M.T. repair cycle.

Machine weld prep and seal rings.

Baffle Section 6th from Top (Continued)

Inspect machining.	#
M.T. weld prep.	
Visual inspect prep.	#
Fitup egg crates.	
Optically align.	#
Weld egg crates.	# WIF
Inspect alignment.	#
Final stress relive.	
Review charts.	#
Inspect alignment.	#
Clean assembly and protect.	
Inspect cleanliness.	#

BAFFLE ASSEMBLY

Fitup (2) upper baffle sections.

Optically align. #

Weld girth seam. # WIF

Optically inspect. #

Final stress relieve local.

Review charts. #

Clean girth O.D.

M.T. girth O.D. #

Standard M.T. repair cycle.

Optically check alignment. #

Visual inspect weld. #

Fitup 3rd baffle sections.

Optically align.

Weld girth seam. # WIF

Optically check alignment. #

Final stress relieve local.

Review charts and release. #

Fitup ring for O.D. seal. #

Baffle Assembly (Continued)

Inspect fitup.	#
Weld O.D. seal ring.	# WIF
Final stress relieve local.	
Review charts.	#
Clean weld seams.	
M.T. seams.	#
X-ray.	#
Review film.	#
Visual inspect welds.	#
Standard M.T. repair cycle.	#
Optically check alignment.	#
Machine flange and O.D. seal ring.	
Inspect machining.	#
Fitup 4th baffle section.	
Inspect fitup optically.	
Weld girth seam.	# WIF
Optically check alignment.	#

Baffle Assembly (Continued)

Local stress relieve.

Review charts

#

Clean up girth O.D.

M.T. girth O.D.

#

Visual inspect weld.

#

Standard M.T. repair cycle.

Optically check alignment.

#

Fitup 5th baffle section.

Optically align.

#

Weld girth seam.

WIF

Optically check alignment.

#

Local stress relieve.

Review charts.

#

Clean up girth O.D.

M.T. girth O.D.

#

Visual inspect weld.

#

Standard M.T. repair cycle.

Optically check alignment.

#

Baffle Assembly (Continued)

Fitup 5th baffle section.

Optically align.

#

Weld girth seam.

WIF

Optically check alignment.

#

Local stress relieve.

Review charts.

#

Clean girth O.D.

M.T. girth O.D.

#

Visual inspect weld.

#

M.T. repair cycle.

#

Optically check alignment.

#

Fitup 6th baffle section.

Optically align.

#

Weld girth seam.

WIF

Optically check alignment.

#

Local stress relieve.

Review charts.

#

Baffle Assembly (Continued)

Clean girth O.D.

M.T. girth O.D.

#

Visual inspect weld.

#

M.T. repair cycle.

#

Optically check alignment.

#

Clean assembly and protect.

Seal all openings.

Inspect cleanliness and protection.

#

STEAM SJDE SHELL

Material release.	#
Steel stamp to identify.	
Grind edges of plate to clean-up.	
M.T. plate edges.	#
Hot form plates (2) 180° segments.	
Anneal plates.	
Release annealing.	#
Cold form.	
Inspect forming.	#
Layout test plate and identify.	
Inspect layout.	#
Remove test plate.	
Process test plate.	
Material certification release.	#
Layout stock material.	
Inspect layout.	#
Burn to remove excess material.	

Steam Side Shell (Continued)

Grind edges for long seams and heat effective zone.

Layout for machine long seams.

Inspect layout. #

Machine long seams.

Inspect machining. #

M.T. long seam weld preps. #

Visual inspect weld preps. #

Fit-up long seams.

Weld tie straps.

Inspect fit-up. #

Set up and weld long seams. # WIF

Remove straps.

Backgroove.

Grind backgroove.

M.T. backgroove.

Weld backgroove. # WIF

Interstage stress relieve.

Steam Side Shell (Continued)

Review charts and release.

#

Dress chip long seams.

Grind long seams and 2T each side and strap removal area.

X-ray long seams.

Review film and release.

#

M.T. long seams I.D. and O.D. and strap removal area.

#

Chip indications.

Grind indications.

M.T. grindouts.

Repair cycle.

#

Machine prep for flange and square other end.

Inspect machining.

#

M.T. Weld prep.

#

Visual Inspect weld prep.

#

STEAM SIDE SHELL ASSEMBLY

Fit-up flange to shell.

Inspect fit-up.

#

Weld tie straps.

Clean backing bar.

Fit-up backing bar.

Weld backing bar.

Weld girth seam.

WIF

Remove tie straps.

Backgroove.

Grind backgroove and strap areas.

M.T. backgroove and strap areas.

#

Weld backgroove and long seam repairs.

WIF

Interstage stress relieve.

Review charts and release.

#

Dress chip girth.

Grind girth seam and 2 "T" and repairs.

X-ray girth and long seam repairs.

Steam Side Shell Assembly (Continued)

Review film and release. #

M.T. girth and long seam repairs. #

Remove indications.

Grind indications.

M.T. grindouts. #

Layout for burning nozzle openings.

Inspect layout. #

Burn openings.

Layout for machining openings.

Machine nozzle openings.

Inspect layout. #

Inspect machining. #

M.T. nozzle openings. #

Visual inspect openings. #

Fit-up nozzles.

Inspect fit-up. #

Weld tie straps.

Clean backing rings.

Steam Side Shell Assembly (Continued)

Fit-up backing rings.

Weld nozzle to shell.

WIF

Interstage stress relieve.

Review charts and release.

Chip backgroove and remove straps.

Grind backgroove and strap areas.

M.T. backgroove and strap areas.

#

Weld nozzle backgrooves.

WIF

Weld flange to shell repairs.

WIF

Interstage stress relieve.

Review charts and release.

#

Grind nozzle seams and girth repairs.

Inspect grinding.

#

X-ray nozzle seams and girth repairs.

Review film and release.

#

M.T. nozzle seams and repairs.

#

Clean areas for lugs and remove nozzle defects.

M.T. lug areas and nozzle seam grindouts.

#

Steam Side Shell Assembly (Continued)

Fit-up internal lugs.

Weld lugs and nozzle repairs.

WIF

Clean welds progressively for M.T. and backgroove seams per specification.

M.T. backgroove and welds progressively per specification.

#

Interstage H.T.

Review charts and release.

#

Grind lug welds and nozzle repairs.

Inspect grinding.

X-ray nozzle repairs and internal lugs.

Review film and release.

#

M.T. lug welds and nozzle repairs.

#

Remove indications.

M.T. grindouts.

Weld repair lug welds.

WIF

Inspect prior to final H.T.

Final stress relieve.

Review charts and release.

#

Grind lug repairs.

Steam Side Shell Assembly (Continued)

M.T. lug repairs.	#
X-ray lug repairs.	
Review film and release.	#
Fit-up safe ends to nozzles.	
Inspect fit-up.	#
Weld safe ends to nozzles.	# WIF
Local stress relieve.	
Review charts and release.	#
Machine I.D. of nozzle seam (Portable HBM).	
Inspect machining.	#
Grind O.D. of safe end seams.	
R.T. safe end seams.	
Review film and release.	#
M.T. safe end seams.	#
Remove indications.	
M.T. grindouts.	#
Weld repair	# WIF
Local stress relieve. (Final)	

Steam Side Shell Assembly (Continued)

Review charts and release.	#
Grind repairs.	
M.T. repairs.	#
R.T. repairs.	
Review film and release.	#
Blast.	
M.T. 100%.	#
U.T. formed plate.	#
Portable HBM machine for leakage monitor.	
Fit-up leakage monitor tube	
Weld leakage monitor tube.	# WIF
Local stress relieve.	
Review charts and release.	#
VBM final machine mating surfaces, lugs, and prep.	
Inspect machining.	#
HBM machine stud holes.	
Inspect machining.	#

Steam Side Shell Assembly (Continued)

Final clean.

Inspect cleanliness.

#

Protect machined surfaces.

Wrap with polyethylene.

Inspect.

#

SODIUM SIDE ASSEMBLY

Fit-up flange to upper sodium shell.

Inspect fit-up and weld preps.

#

Weld girth seam.

WIF

Backgroove.

M.T. backgroove.

#

Weld backgroove.

WIF

Interstage stress relieve.

Review charts and release.

#

Grind girth.

Inspect grinding and completed weld seam.

#

X-ray girth.

Review film and release.

#

Remove defects.

M.T. grindouts.

#

Fit-up seal ring.

Inspect fit-up and weld preps.

#

Weld seal ring and repairs.

WIF

Backgroove seal ring.

Sodium Side Assembly (Continued)

M.T. backgroove.	#
Weld backgroove.	# WIF
Interstage stress relieve.	
Review charts and release.	#
Grind seal ring and repairs.	
Visual inspect welds.	#
X-ray repairs.	
Review film and release.	#
M.T. seal girth and repairs.	#
Remove defects.	
M.T. grindouts.	#
Fit-up cone.	
Inspect fit-up and weld preps.	#
Weld cone girth and seal ring repairs.	# WIF
Backgroove cone girth weld.	
M.T. backgroove.	#
Weld backgroove.	# WIF

Sodium Side Assembly (Continued)

Interstage stress relieve.

Review charts and release.

#

Grind cone girth and repairs.

Visual inspect welds.

#

X-ray cone girth.

Review film and release.

#

M.T. cone girth and repairs.

#

Remove defects.

M.T. grindouts.

#

Fit-up keyway ring forging.

Inspect fit-up and weld preps.

#

Weld ring girth and repairs.

WIF

Backgroove girth.

M.T. backgroove.

#

Weld backgroove.

WIF

Interstage stress relieve.

Review charts and release.

#

Grind ring girth and repairs.

Sodium Side Assembly (Continued)

Visual inspect welds.

X-ray ring girth and repairs.

Review film. #

M.T. girth and repairs. #

Remove defects.

M.T. grindouts. #

Fit-up short shell ring.

Inspect fit-up and weld preps. #

Weld girth seam and repairs. # WIF

Backgroove.

M.T. backgroove. #

Weld backgroove. # WIF

Interstage stress relieve.

Review charts. #

Grind girth and repairs.

Visual inspect weld seam. #

R.T. girth and repairs.

Review film and release. #

Sodium Side Assembly (Continued)

M.T. girth and repairs.	#
Remove defects.	
M.T. grindouts.	
Layout nozzle openings.	
Inspect layout.	#
Burn openings.	
Layout for machining openings.	
Inspect layout.	#
Machine nozzle openings.	
Inspect machining.	#
M.T. openings.	#
Fit-up nozzles in cone area.	
Inspect fit-up and weld preps.	#
Weld nozzles to shell, repair shell girth.	# WIF
Interstage stress relieve.	
Review charts and release.	#
Backgroove nozzle seams.	
M.T. backgroove.	#

Sodium Side Assembly (Continued)

Weld nozzle backgroove. # WIF

Interstage stress relieve.

Review charts. #

Grind nozzle seams and repairs.

Inspect grinding. #

Visual inspect welds. #

X-ray nozzle seams and repairs.

Review film and release. #

M.T. nozzle seams and release. #

R.T. and M.T. repair cycle.

Fit-up support skirt assembly.

Inspect fit-up and weld preps. #

Weld support skirt to flange. # WIF

Interstage stress relieve.

Review charts and release. #

Grind seam.

M.T. support skirt seam. #

Sodium Side Assembly (Continued)

X-ray seam.

Review film and release.

Remove defects.

M.T. grindouts.

#

Fit-up remaining nozzle and keys.

Inspect fit-up and weld preps.

#

Weld nozzles and keys and repairs.

WIF

Interstage stress relieve.

Review charts and release.

#

Backgroove nozzles and grind key welds.

M.T. backgroove and key welds.

#

X-ray nozzle repairs.

Review film and release.

Remove defects.

M.T. grindouts.

#

Weld nozzle backgroove and key repairs.

WIF

Interstage stress relieve.

Review charts and release.

#

Sodium Side Assembly (Continued)

Grind nozzle weld and repairs.

Inspect grinding. #

Visual inspect welds. #

R.T. nozzle welds and repairs.

Review film and release. #

M.T. nozzle and repairs. #

Remove defects.

M.T. grindouts. #

Weld repairs. # WIF

Final stress relieve. #

Review charts. #

Grind repairs.

Visual inspect welds. #

X-ray repairs.

Review film and release. #

M.T. repairs. #

Blast 100% to clean up.

Inspect cleaning. #

Sodium Side Assembly (Continued)

M.T. 100%.	#
Final machine flange, support skirt, I.D. seal and prep, keys.	
Inspect machining and record critical characteristics.	#
M.T. machined surfaces.	#
Fit sodium intermediate shell.	
Inspect fit-up and weld preps.	#
Weld girth seam.	# WIF
Local stress relieve. (Final)	
Review charts and release.	#
Grind seam for M.T. and R.T.	
Inspect grinding and welds.	#
X-ray girth.	
Review film and release.	#
M.T. girth.	#
Remove defects.	
M.T. grindouts.	#
Weld repair girth.	# WIF
Interstage stress relieve local (Final)	

Sodium Side Assembly (Continued)

Review charts and release.	#
Grind repairs.	
Visual inspect welds.	#
X-ray repairs.	
Review film and release.	#
M.T. repairs.	#
Layout for machining keys.	
Inspect optically.	#
Machine keys	
Inspect machining.	#
Fit-up bottom head assembly.	
Inspect fit-up and weld preps.	#
Weld girth seam.	# WIF
Local stress relieve final.	
Review charts and release.	#
Clean girth seam.	
Inspect grinding and .visual inspect weld.	#
X-ray girth seam.	

Sodium Side Assembly (Continued)

Review film and release.	#
M.T. girth weld.	#
Remove defects.	
M.T. grindouts.	#
Weld repairs.	# WIF
Local stress relieve final.	
Review charts and release.	#
Grind repairs.	
Visual inspect weld.	#
X-ray repairs.	
Review film.	#
M.T. repairs.	#
Final clean.	
Inspect cleanliness.	#

UPPER SHELL

Material release.	#
Layout for removing excess stock.	
Inspect layout and identification.	#
Remove excess stock.	
Layout for machining preps.	
Inspect layout.	#
Machine weld preps.	
Inspect machining.	#
M.T. preps.	#
Sublet rolling.	
Inspect rolling.	#
Clean weld preps.	
Fit-up.	
Visual inspect weld preps and fit-up.	#
Weld long seams I.D.	# WIF
Interstage H.T.	
Review charts and release.	#
Backgroove.	

Upper Shell (Continued)

M.T. backgroove.	#
Weld backgroove.	# WIF
Interstage stress relieve.	
Review charts and release.	#
Grind long seams.	
Inspect grinding and completed weld.	#
X-ray long seams.	
Review film and release.	#
M.T. long seams.	#
Standard R.T. and M.T. repair cycle.	
Machine weld preps.	
Inspect machining.	
M. P. weld preps.	#

SHELL CONE ASSEMBLY

Material release.	#
Layout for burning segments.	
Flame cut segments.	
Clean-up edges.	
Form segments.	
Inspect forming and identification.	#
Layout excess stock.	
Remove excess stock.	
Grind weld preps.	
Inspect segments.	#
Fit-up segments.	
Inspect fit-up and weld preps.	#
Weld long seams.	# WIF
Interstage stress relieve.	
Review charts and release.	#
Remove runouts.	
Grind long seams.	
Inspect grinding and completed weld.	#

Shell Cone Assembly (Continued)

X-ray long seams.

Review film and release.

#

M.T. long seams.

#

Standard R.T. and M.T. repair cycle.

Machine weld preps.

Inspect machining.

#

M.T. preps.

#

KEYWAY RING FORGINGS

Material release. #

Machine weld preps.

Inspect machining. #

M.T. preps. #

INTERMEDIATE AND LOWER SHELLS

Material release.	#
Layout for removing excess stock.	
Inspect layout and identification.	#
Remove stock.	
Layout for machining preps.	
Inspect layout.	#
Machine preps.	
Inspect machining.	#
M.T. preps.	#
Sublet rolling.	
Clean preps for long seam.	
Inspect for welding seam.	#
Weld long seam.	# WIF
Interstage stress relieve.	
Review charts and release.	#
Backgroove long seam.	
M.T. backgroove.	#
Weld backgroove.	# WIF

Intermediate and Lower Shells (Continued)

Interstage stress relieve.

Review charts and release. #

Grind long seam.

Inspect grinding and completed weld. #

X-ray long seam.

Review film and release. #

M.T. long seams. #

Standard R.T. and M.T. repair cycle.

Final stress relieve.

Review charts and release. #

Blast 100%.

Visual inspect cleanliness. #

M.T. 100%. #

Machine weld prep.

Inspect machining. #

M.T. preps. #

CLADDED LOWER SHELL

Material release.	#
Clean surface for clad.	
M.T. surface to be cladded.	#
Clad (1) side of plate.	# WIF
Interstage stress relieve.	
Review charts and release.	#
Grind clad for U.T. and M.T.	
M.T. clad surface.	#
Remove indications.	
M.T. grindouts.	#
Weld repair clad.	# WIF
Interstage stress relieve.	
Review charts and release.	#
Grind repairs.	
M.T. repairs.	#
U.T. clad.	#
Sublet rolling and forming.	

Cladded Lower Shell (Continued)

Prepare long seam for welding.

Inspect weld preps and fit-up. #

Weld long seam. # WIF

Interstage stress rleive.

Review charts and release. #

Backgroove long seam.

Weld long seam. # WIF

Grind I.D. of seam for backclad.

Visual inspect weld. #

M.T. I.D. of seam. #

Backclad long seam. # WIF

Interstage stress relieve.

Review charts and release. #

Grind long seam.

Inspect grinding and completed clad. #

X-ray long seam.

Review film and release. #

M.T. long seam. #

Cladded Lower Shell (Continued)

U.T. long seam clad.

#

Standard R.T., M.T., and U.T. repair cycle.

Machine weld prep.

Inspect machining.

#

M.T. Preps.

#

BOTTOM HEAD

Material release.	#
Clean plate for cladding.	
M.T. plate.	#
Clad plate.	# WIF
Interstage stress relieve.	
Review charts and release.	#
Grind clad for M.T. and U.T.	
M.T. clad.	#
Standard M.T. repair cycle.	
U.T. clad.	#
Sublet rolling or forming	
Layout for removing stock.	
Inspect layout and identification.	#
Remove stock from plate for forming H.D.	
Clean burned edges.	
Form head.	
Furnace.	
Review charts and release.	#

Bottom Head(Continued)

Inspect formed head.	#
Layout nozzle opening.	
Inspect layout.	#
Burn to remove stock from nozzle opening.	
Layout for machining opening.	#
Machine nozzle opening.	
Inspect machining.	#
M.T. opening prep.	#
Fit-up sodium inlet nozzle. (Outlet)	
Inspect fit-up and weld preps.	#
Weld nozzle to head.	# WIF
Grind seam I.D. for backclad.	
M.T. seam I.D.	#
Backclad nozzle seam.	# WIF
Backgroove seam O.D.	
M.T. backgroove.	# WIF
Weld backgroove.	# WIF
Interstage stress relieve.	
Review charts.	#

Bottom Head (Continued)

Grind seam I.D. and O.D.

Inspect grinding and completed weld.

#

X-ray seam.

Review film and release.

#

M.T. seam.

#

Standard R.T. and M.T. repair cycle.

Machine weld prep.

Inspect weld prep.

#

M.T. prep.

#

BOTTOM HEAD AND SHELL ASSEMBLY

Fit short shell to bottom head.

Inspect fit-up and weld preps.

#

Weld girth.

WIF

Interstage stress relieve.

Review charts and release.

#

Backgroove seam.

M.T. backgroove.

#

Weld backgroove.

WIF

Grind for back clad.

M.T. seam I.D.

#

Visual inspect seam.

#

Back clad seam I.D.

WIF

Interstage stress relieve.

Review charts and release.

#

Grind girth clad.

Visual inspect clad.

X-ray girth seam.

Review film and release.

#

Bottom Head and Shell Assembly (Continued)

M.T. girth #

U.T. girth clad. #

Standard R.T., M.T., and U.T. repair cycle.

Machine weld prep.

Inspect machining. #

Blast 100%.

M.T. 100%. #

Final clean.

Inspect cleaning. #

Install liner.

Inspect fit-up.

HEAD LINER

Material release.	#
Layout for machine hole and weld prep.	
Machining prep.	
Inspect machining.	#
Liquid penetrant inspect.	#
Drill holes for anchor pins.	
Inspect drilling.	#
Fit-up nozzle liner.	
Inspect fit-up.	#
Weld nozzle liner.	# WIF
Interstage H.T.	
Review chart.	#
Grind weld seam.	
Visual inspect seam.	#
M.T. seam.	#
Blast to clean up.	
Inspect cleanliness.	#

INLET NOZZLE LINER

Material release.	#
Layout for flame cutting.	
Flame cut material for liner.	
Clean burned edges.	
Sublet rolling.	
Prepare long seam.	
Visual inspect preps.	#
Weld long seam.	# WIF
Backgroove.	
M.T. backgroove.	#
Weld backgroove.	# WIF
Grind seam.	
Visual inspect seam.	#
M.T. seam.	#
Machine weld prep.	
Inspect machining.	#
Drill holes for anchor pins.	
Inspect machining.	#

Inlet Nozzle Liner (Continued)

M.T. weld preps.

#

EGG CRATES

Material release.	#
Fit egg crate half in fixture.	
Inspect fit-up.	#
Weld bars (slats) to ring.	# WIF
Fitup (1) cross bar and (3) connecting bars.	
Inspect fitup.	#
Weld cross bar and connecting bars.	# WIF
Remove from fixture and turn.	
Complete seal welding.	#
Inspect completed welds.	#
Fitup halves to make (1) complete egg crate assembly.	
Inspect fitup.	
Weld connecting bars.	# WIF
Inspect assembly.	#
Clean egg crate.	
Inspect cleanliness.	#
Wrap for storage in clean room.	

SODIUM SHELL LINER

Material release.	#
Sublet rolling	
Prepare long seam prep.	
Inspect rolling and welding preps.	#
Weld long seam.	# WIF
Interstage stress relieve.	
Review charts and release.	#
Grind long seams.	
Visual inspect completed welds.	#
M.T. seams.	#
Standard M.T. repair cycle.	
Layout length.	
Inspect layout.	#
Cut to length.	
Inspect.	#
Layout for drilling holes.	
Drill holes.	
Inspect drilling.	#

Sodium Shell Liner (Continued)

M.T. 100%.

#

Final clean.

Inspect cleaning.

#

SKIRT ASSEMBLY

Material release.	#
Layout segments.	
Flame cut segments.	
Grind edges.	
Form segments.	
Layout excess stock.	
Inspect layout.	#
Remove stock.	
Grind edges.	
M.T. edges.	#
Visual inspect weld preps.	#
Fit-up long seams.	
Inspect fit-up.	#
Weld long seams.	# WIF
Back groove.	
M.T. back groove.	#
Weld back groove.	#
Interstage heat treat.	# WIF

Skirt Assembly (Continued)

Review charts.

Grind long seam for NDT.

Inspect seams (visual.) #

X-ray seams.

Review film. #

M.T. seams. #

Standard R.T. and M.T. repair cycle.

Machine prep for base ring.

Inspect machining. #

M.T. prep. #

Visual inspect preps. #

Fit-up base ring to cone.

Inspect fit-up. #

Weld seam. # WIF

Backgroove.

Grind backgroove.

M.T. backgroove.

Weld back groove. # WIF

Skirt Assembly (Continued)

Interstage stress relieve.

Review charts.

#

Grind seam.

Visual inspect completed seam.

#

X-ray seam.

Review film.

#

M.T. weld seam.

#

Standard R.T. and M.T. repair cycle.

Blast.

M.T. 100% (I.D. and O.D.)

#

Machine weld prep.

Inspect machining.

#

Layout openings.

Out openings.

Grind openings.

M.T. prep and openings.

#

SUPPORT SKIRT BASE RING

Material release.	#
Layout segments.	
Flame cut segments.	
Grind weld preps.	
M.T. preps.	#
Visual inspect weld preps.	
Fit-up ring.	
Inspect fit-up.	#
Weld ring segments.	# WIF
Backgroove.	
Grind backgroove.	
M.T. backgroove.	#
Weld backgroove.	# WIF
Interstage stress relieve.	
Review charts.	#
Grind welds.	
Inspect grinding.	#
Visual inspect welds.	#

Support Skirt Base Ring (Continued)

M.T. seams.

#

Standard M.T. repair cycle.

Survey machine ring.

Inspect.

#

STEAM SIDE INTERNALS

TUBE SHEET

Material release.	#
Machine tube sheet VBM.	
Inspect machining.	#
M.T. 100%.	#
HBM machine holes complete.	
Inspect machining.	#
Protect holes.	
Visual inspect weld preps.	#
Fitup cylinder assembly to tube sheet.	
Inspect fitup.	#
Weld girth.	# WIF
Grind backgroove.	
M.T. back groove.	#
Weld back groove.	#
Interstage stress relieve.	
Review charts.	#
Grind seams.	
Visual inspect seams.	#

Steam Side Internals (Continued)

M.T. seams.

#

Standard M.T. repair cycle.

Final stress relieve.

Review charts.

#

Blast assembly.

M.T. 100%.

#

INTERNAL CYLINDER STEAM SIDE

Material release.	#
Sublet rolling.	
Grind weld prep.	
M.T. prep.	#
Prepare seam for welding.	
Visual inspect seam.	#
Weld cylinder long seam.	# WIF
Back groove.	
M.T. backgroove.	#
Weld backgroove.	# WIF
Interstage stress relieve.	
Review charts.	#
Grind seam.	
Visual inspect seam.	#
M.T. seam.	#
Standard M.T. repair cycle.	
Machine weld preps.	
M.T. preps.	#

Internal Cylinder Steam Side (Continued)

Visual inspect preps.	#
Fit top support ring.	
Inspect fitup.	#
Weld ring to cylinder.	# WIF
Backgroove..	#
M.T. backgroove.	#
Weld backgroove.	# WIF
Interstage stress relieve.	
Review charts.	#
Grind seam.	
Visual inspect seam.	#
M.T. seam.	#
Standard M.T. repair cycle.	
Layout opening for sleeve.	
Inspect layout.	#
Cut sleeve opening.	
Grind opening.	
Inspect.	#

Internal Cylinder Steam Side (Continued)

Blast.

M.T. 100% (I.D. and O.D.)

#

Layout bolting circle.

Inspect layout.

#

Drill bolting circle.

Inspect drilling.

#

COVER PLATE

Material release.

#

Layout for burning.

Burn plate.

Machine plate O.D.

Layout plate for drilling.

Inspect.

#

Drill bolting circle.

Inspect drilling.

#

Blast.

M.T. 100%.

#

STEAM PIPE SUPPORT WELDMENT

Material release.	#
Layout plates.	
Burn plates to size.	
Grind edges.	
Visual inspect.	#
Fit-up weldment.	
Inspect fit-up.	#
Weld plates.	# WIF
Interstage stress relieve.	
Review charts.	#
M.T. seam.	#
Standard repair cycle.	
Blast.	
M.T. 100%.	#
Layout and drill.	
Inspect drilling.	#

VESSEL FLANGES

Material release.

#

Machine weld prep.

Inspect machining.

#

M.T. preps.

#

TOP HEAD FORGING

Material release.	#
Machine area for nozzle build-up.	
Inspect machining.	#
Weld build-up for nozzle.	# WIF
Interstage stress relieve.	
Review charts.	#
Machine build-up for NDT.	
U.T. build-up.	
M.T. build-up.	#
Standard M.T. repair cycle.	
Drill pilot hole for nozzle.	
Inspect drilling.	#
Visual inspect preps.	#
Fit-up nozzle plug.	
Weld nozzle plug.	# WIF
Interstage stress releive.	
Review charts.	#
Machine nozzle preliminary.	

Top Head Forging (Continued)

Inspect machining.	#
M.T. preliminary.	#
X-ray preliminary.	
Review film.	#
Standard M.T. and R.T. repair cycle.	
Final stress relieve.	
Review charts and release.	#
Final machine nozzle stud holes.	
Inspect.	#
X-ray nozzle welds.	
Review film and release.	#
M.T. nozzle welds.	#
Blast.	
M.T. 100%.	#
Final machine mating surface.	
Inspect machining.	#
Final clean.	
Inspect cleaning.	#

NOZZLES AND SAFE-ENDS

Material release.

#

Machine weld preps.

Inspect machining.

#

M.T. preps.

#

LMFBR STEAM GENERATOR

30 MWt SODIUM TEST

MODEL

STEAM DRUM AND PIPING

I.M.Q. PLAN

APPENDIX D.2

COMBUSTION ENGINEERING, INC.
CHATTANOOGA, DIVISION
CHATTANOOGA, TENNESSEE

LMFBR STEAM GENERATOR
30MWt SODIUM TEST MODEL
STEAM DRUM AND PIPING

INTEGRATED MANUFACTURING - QUALITY PLAN

CONTRACT 7670

PREPARED BY:

J. F. Lowery
Process Engineer

QUALITY PLANNING REVIEWED BY:

R. G. Kutt

DATE: February 1, 1973

REVISION: 0

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SECTION II PAGE

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SYMBOLS AND DEFINITIONS

#	Inspection Point
I.D.	Inside Diameter
O.D.	Outside Diameter
M.T.	Magnetic Particle Test
P.T.	Dye Penetrant Test
R.T.	Radiographic Test
W.I.F.	Weld Inspection Form

STANDARD M.T. REPAIR CYCLE

Remove defects.

M.T. grindouts. #

Weld repairs. # WIF

Interstage stress relieve.

Review charts. #

Grind repairs.

M.T. repairs. #

STANDARD R.T. REPAIR CYCLE

Remove Defects

M.T. Grindouts. #

Weld Repairs. # WIF

Interstage Stress Relieve.

Review charts. #

Grind repairs.

M.T. repairs. #

X-ray repairs.

Review film. #

TOOL AND FIXTURE LIST

1. Elbo machining fixture
2. Header to Steam Drum locating fixture
3. Header and Steam Drum Handling Rig
4. Piping Assembly Handling Equipment
5. Local Stress relief equipment

STEAM DRUM HEADS (2)

Incoming material inspection.	#
Layout material for burning.	
Inspect layout and identification of material.	#
Burn material for forming.	
Clean to remove burn slag.	
M.T. plate edges. (C-E information)	#
Form heads.	#
Inspect forming.	#
Sand blast 100% .	
M.T. head 100%.	#
Layout to rough burn manway opening.	
Inspect layout.	#
Burn manway opening.	
Layout to machine all nozzle openings and to complete manway opening.	
Inspect layout.	#
Machine all openings and girth seam weld prep.	
Inspect machining.	#

Steam Drum Heads (Continued)

M.T. inspect all openings/weld preps.	#
Visual inspect weld preps.	#
Fit-up and brace all nozzles and lugs for welding.	
Inspect fit-up.	#
Weld all nozzles into head.	# WIF
Back groove all nozzle welds.	
M.T. inspect back grooves.	#
Weld nozzle back grooves and lugs.	# WIF
Interstage stress relieve.	
Review furnace chart and release.	#
Grind all welds for M.T. and R.T.	
Inspect radii completed weld.	#
R.T. all nozzle welds.	
Review film and release.	#
M.T. all welds.	#
Standard R.T. repair cycle.	

Hold Head for Fit-up to Drum.

STEAM DRUM SHELL HALVES

Incoming material inspection.	#
Layout material for burning.	
Inspect layout and identification.	#
Burn material for forming.	
Clean to remove slag.	
M.T. plate edges. (C-E information)	#
Form shell halves.	
Inspect forming.	#
Sand blast 100%.	
Layout and machine long seam weld preps.	
Inspect machining.	#
M.T. material 100% including long seam weld preps.	#

Hold for Shell Assembly.

Incoming material inspection.	#
Layout body material for burning to length.	
Inspect layout.	#
Burn to length.	
Layout to machine ends and all pipe penetrations.	
Inspect layout.	#
Machine complete.	
Inspect machining.	#
M.T. all weld preps.	#
Fitup nozzles to headers.	
Inspect fit-up.	#
Weld nozzles to headers.	# WIF
Back groove nozzle welds.	
M.T. back grooves.	
Weld back grooves.	# WIF
Interstage stress relieve	
Review charts.	#
Prepare all welds for R.T. and M.T.	
R.T. all Welds.	

Header Assemblies (Continued)

Review film.	#
M.T. all welds,	#
Remove indications.	
M.T. all grindouts.	#
Weld repair.	# WIF
Interstage stress relieve.	
Review chart.	#
Grind repairs.	
R.T. repairs.	
Review film.	#
M.T. repairs.	#
Fit-up header ends.	
Inspect fit-up.	#
weld girth seams.	# WIF
Interstage stress relieve.	
Review chart.	#
Prepare welds for R.T. and M.T.	

Header Assemblies (Continued)

R.T. girth seams.

Review film. #

M.T. girth seams. #

Remove indications.

M.T. grind outs. #

Weld repair. # WIF

Final stress relieve.

Review chart. #

Prepare repairs for R.T. and M.T.

R.T. repairs.

Review film. #

M.T. repairs. #

Hold for Fit-up To Steam Drum Assembly.

HEADER TO STEAM DRUM PIPING

Incoming material inspection.	#
Layout to saw all pieces to length.	
Inspect layout and identification.	#
Machine all weld preps.	
Inspect machining.	#
Fit-up sub-assemblies.	
Inspect fit-up.	#
Weld girths.	# WIF
Interstage stress relieve.	
Review chart and release.	#
Prepare welds for R.T./M.T.	
Visual inspect completed welds.	#
R.T. welds.	
Review film and release.	#
M.T. girths.	#
Standard R.T. repair cycle.	

Hold for Fit-up to Headers Steam Drum.

RECIRCULATION FEEDWATER PIPING

Incoming material inspection.	#
Layout to saw all pieces to length.	
Inspect layout and identification.	#
Machine weld preps on all straights, elbows, and tees.	
M.T. inspect all preps.	#
Visual inspect weld preps.	#
Fit up assemblies as practical for shipment.	
Inspect fit-up.	#
Weld Assemblies.	# WIF
Interstage stress relieve.	
Review chart.	#
Grind welds for R.T. inspection.	
Visual inspect completed welds.	#
R.T. inspect welds.	
Review film and release.	#
M.T. weld seams.	#
Remove indications.	
M.T. grind outs.	#
Weld repair.	# WIF

Recirculation Feedwater Piping (Continued)

Grind repairs.

Final Stress relieve.

Review chart. #

Visual inspect repairs. #

R.T. inspect repairs.

Review film. #

M.T. repairs. #

Clean for shipment.

Final inspection. #

Prepare for shipment.

Inspect preparation for shipment. #

Ship.

FEEDWATER PIPING

Incoming material inspection.	#
Layout to saw all pieces to length.	
Inspect layout and identification.	#
Machine weld preps on all straights, elbows, and tees.	
M.T. inspect all preps.	#
Visual inspect weld preps.	#
Fit-up assemblies as practical for shipment.	
Inspect fit-up.	#
Weld assemblies.	# WIF
Interstage stress relieve.	
Review chart.	#
Grind welds for R.T. inspection.	
Visual inspect completed welds.	#
R.T. inspect welds.	
Review film and release	#
M.T. weld seams.	#
Remove indications.	
M.T. grind outs.	#

Feedwater Piping (Continued)

Weld repair. #WIF

Grind repairs.

Final stress relieve.

Review chart. #

Visual inspect repairs. #

R.T. inspect repairs.

Review film. #

M.T. repairs. #

Clean for shipment.

Final inspection. #

Prepare for shipment. #

Inspect preparation for shipment. #

Ship.

WATER STEAM PIPING

Incoming material inspection.	#
Layout to saw all pieces to length.	
Inspect layout and identification.	#
Machine weld preps on all straights, elbows, and tees.	
M.T. inspect all preps.	#
Visual inspect weld preps.	#
Fit-up assemblies as practical for shipment.	
Inspect fit-up.	#
Weld assemblies.	# WIF
Interstage stress relieve.	
Review chart.	#
Grind welds for R.T. inspection.	
Visual inspect completed welds.	#
R.T. inspect welds.	
Review film and release.	#
M.T. weld seams.	#
Remove indications.	
M.T. grind outs.	#

Water Steam Piping (Continued)

Weld repair. # WIF

Grind repairs.

Final stress relieve.

Review chart. #

Visual inspect repairs. #

R.T. inspect repairs. #

Review film. #

M.T. repairs.

Clean for shipment.

Final inspection. #

Prepare for shipment. #

Inspect preparation for shipment. #

Ship.

SATURATED STEAM PIPING

Incoming material inspection.	#
Layout to saw all pieces to length.	
Inspect layout and identification.	#
Machine weld preps on all straights, elbows, and tees.	
M.T. inspect all preps.	#
Visual inspect weld preps	#
Fit-up assemblies as practical for shipment.	
Inspect fit-up.	#
Weld assemblies.	# WIF
Interstage stress relieve.	
Review chart.	#
Grind welds for R.T. inspection.	
Visual inspect completed welds.	#
R.T. inspect welds.	
Review film and release.	#
M.T. weld seams.	#
Remove indications.	
M.T. grind outs.	#

Saturated Steam Piping (Continued)

Weld repair. # WIF

Grind repairs.

Final stress relieve.

Review chart. #

Visual inspect repairs. #

R.T. inspect repairs. #

Review film. #

M.T. repairs.

Clean for shipment.

Final inspection. #

Prepare for shipment. #

Ship.

STEAM DRUM SHELL ASSEMBLY

Visual inspect weld preps..	#
Fit-up and strap long seams for welding.	
Inspect fit-up.	#
Weld shell long seams.	# WIF
Back groove long seams and remove tie straps.	#
M.T. inspect back groove and tie strap areas.	#
Weld back groove and repair tie strap areas.	# WIF
Interstage stress relieve.	
Review chart and release.	#
Grind seams for M.T. and R.T.	
Visual inspect completed welds.	#
R. T. long seams.	
Review film and release.	#
M.T. inspect long seam welds.	#
Remove R.T. indications.	
M.T. areas of indication removal.	#
Layout to rough burn down take nozzle openings.	
Inspect layout.	#

Steam Drum Shell Assembly (Continued)

Burn holes.

Layout to machine all remaining nozzle openings, and to complete down take nozzle openings.

Inspect layout. #

Machine all nozzle openings.

Inspect machining. #

M.T. inspect all nozzle openings. #

Visual inspect weld preps. #

Fit-up all nozzles.

Inspect fit-up. #

Weld all nozzles (O.D.) and long seam repairs. # WIF

Interstage stress relieve.

Review chart and release. #

Back groove all nozzle welds.

M.T. back grooves. #

Weld all nozzle back grooves. # WIF

Interstage stress relieve.

Review chart and release. #

Steam Drum Shell Assembly (Continued)

Grind nozzle welds and long seam repairs for M.T. and R.T.

Visual inspect completed welds. #

R.T. all nozzle welds and long seam repairs.

Review film and release. #

M.T. all nozzle welds and long seam repairs. #

Remove indications.

M.T. grind outs. #

Layout I.D. for all welded attachments.

Inspect layout. #

Fit-up all internal weld attachments.

Inspect fit-up. #

Weld internal attachments. # WIF

M.T. root layer and @ 1/2" of weld. #

Back groove all attachments.

M.T. back grooves. #

Complete attachment welds and weld repair nozzle welds. # WIF

M.T. @ 1/2" of weld if required. #

Interstage stress relieve.

Steam Drum Shell Assembly (Continued)

Review chart and release.

#

Grind all internal attachment and nozzle repair welds.

Visual inspect completed welds.

#

R.T. all nozzle repairs.

Review film and release.

#

M.T. all internal attachment and nozzle repair welds.

#

Machine girth seam weld preps.

Inspect machining.

#

M.T. inspect weld preps.

#

Hold For Head Attachment.

STEAM DRUM ASSEMBLY

Visual inspect weld preps.	#
Fit-up (1) head to shell assembly.	
Inspect fit-up.	#
Weld head to shell.	# WIF
Back groove girth seam.	
M.T. inspect back groove.	#
Weld back groove.	# WIF
Interstage stress relieve.	
Review chart and release.	#
Visual inspect weld preps.	#
Fit-up remaining head to assembly.	
Inspect fit-up.	#
Weld girth seam.	# WIF
Back groove girth seam.	
M.T. inspect back groove.	#
Weld back groove.	# WIF
Interstage stress relieve.	
Review chart and release.	#

Steam Drum Assembly (Continued)

Grind (2) girth seam for M.T. and R.T.

Visual inspect completed welds.

#

R.T. girth seams.

Review film and release.

#

M.T. inspect girth seams. (I.D.) and O.D.)

#

Remove indications.

Layout for all external shell attachments.

Inspect layout.

#

Fit-up all external attachments.

Inspect fit-up.

#

Weld all external attachments and girth seam repairs.

WIF

M.T. root pass and @ 1/2" of weld.

Inspect prior to final stress relieve.

#

Final stress relieve.

Review chart and release.

#

Grind all external attachment and girth seam repair welds.

Visual inspect completed welds.

#

R.T. girth seam repairs.

Steam Drum Assembly (Continued)

Review film and release.	#
M.T. girth seam repairs and all external attachment welds.	#
Set-up and final machine all nozzles and manways in heads.	
Inspect machining.	#
M.T. inspect all machined areas.	#
Visual inspect weld preps and identification.	#
Fit-up header assemblies to steam drum.	
Inspect fit-up.	#
Weld girth seams.	# WIF
Local final stress relieve.	
Review charts and release.	#
Prepare welds for R.T./M.T.	
Visual inspect completed welds.	#
R.T. girth welds.	
Review film and release.	#
M.T. girths.	#
Standard R.T. repair cycle.	
Clean I.D. of assembly for fit-up of internals.	

Steam Drum Assembly (Continued)

Inspect cleaning.	#
Fit-up feedwater piping assemblies and nozzle boxes/spiders.	
Insepct fit-up.	#
Fit-up bent plates.	
Inspect fit-up.	#
Weld bent plates.	# WIF
Clean welds for M.T. inspection.	
Visual inspect completed welds.	#
M.T. inspect bent plate welds.	#
Fit-up curved panels/heads and shell.	
Inspect fit-up.	#
Weld curved panels.	# WIF
Prepare welds for M.T. inspection.	
Visual inspect completed welds.	#
M.T. inspect curved panel welds.	#
Fit-up separators.	
Inspect fit-up.	#
Fit-up basket/frame assemblies.	

Steam Drum Assembly (Continued)

Inspect fit-up.	#
Fit-up drain baskets and drain pipes.	
Inspect fit-up.	#
Clean for hydro.	
Inspect cleaning.	#
Prepare for hydro.	#
Hydro assemblies.	
Inspect hydro.	#
Remove from hydro.	
M.T. all pressure welds (I.D. and O.D.).	#
Final clean I.D. of assembly.	
Inspect cleaning.	#
Prepare O.D. for painting.	
Stamp all required identification.	
Inspect identification.	#
Paint O.D. of assembly.	
Final inspect completed assembly.	#
Ship assembly.	

APPENDIX E

MECHANICAL DESIGN ANALYSIS

- E.1 Tube/Flange Sizing
- E.2 Evaporator and Superheater Steam Side Sizing
- E.3 Preliminary Structural Analysis of Tube-To-Tubesheet Weld
- E.4 Preliminary Structural Analysis of the Pressure Tube at Sodium-Argon Interface

NUCLEAR COMPONENTS DEPARTMENT

STRUCTURAL ANALYSIS
EVAPORATOR HIGH PRESSURE TUBESHEET

UNIT DESIGNATION

REVIEWED

[illegible]

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER JS- 115 E-1SHEET 1 OF 13DATE 2-15-73 BY P. AndersonCHARGE NO. D-51100

CHECK DATE _____ BY _____

DESCRIPTION EVAPORATOR H.P. TUBESHEETSUMMARY & CONCLUSIONS

THE EVAPORATOR HIGH PRESSURE TUBESHEET, SODIUM FLANGE, AND SHELL TO FLANGE REGIONS ARE ANALYZED FOR DESIGN PRESSURES AND FLANGE STUD PRELOAD. PRIMARY STRESSES ARE EVALUATED FOR STEAM PRESSURE OF 2750 PSI AND SODIUM PRESSURE OF 80 PSI AT DESIGN TEMPERATURE OF 650° F.

ALL PRIMARY STRESSES ARE SATISFACTORY AND MEET THE APPROPRIATE ALLOWABLES SET FORTH IN THE ASME CODE, SECTION III FOR NUCLEAR VESSELS.

SIGNIFICANT RESULTS

THE MAXIMUM PRIMARY STRESS OCCURS IN THE PERFORATED TUBESHEET AT THE VESSEL CENTERLINE. THE CALCULATED STRESS INTENSITY OF 15.4 ksi IS LESS THAN THE ALLOWABLE OF $1.5 S_m = 28.6$ ksi AT 650° F. ALL OTHER STRESSES ARE SIGNIFICANTLY LESS THAN ALLOWABLES.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-115 E-1
SHEET 2 OF 13
DATE 2-15-73 BY P. Anderson
CHECK DATE _____ BY _____

CHARGE NO. D-51100
DESCRIPTION EVAPORATOR H.P. TUBESHEET

DISCUSSION

THE TUBESHEET / FLANGE GEOMETRY IS SHOWN IN FIG. 1 WITH THE CORRESPONDING FINITE ELEMENT MODEL SHOWN IN FIG. 2. SIGNIFICANT STRESS LOCATIONS ARE SHOWN ON THE MODEL.

THE ANALYSIS IS PERFORMED FOR DESIGN CONDITIONS

$$P_1 = 2750 \text{ PSI} - \text{STEAM SIDE}$$

$$P_2 = 80 \text{ PSI} - \text{SODIUM SIDE}$$

$$T = 650^\circ \text{ F}$$

STRESS RESULTS ARE PRESENTED IN FIGURES 3 THROUGH 7.

FIG. 1
30 MWT EVAPORATOR
TUBESHEET - FLANGE

FIG. 2
30 MWT EVAPORATOR
FINITE ELEMENT MODEL
& STRESS LOCATIONS

FIG. 3

TUBESHEET + FLANGE

DEFORMED SHAPE

FIG. 4

6 OF 13

E-1

30 MWT EVAPORATOR
TUBESHEET & STRESS
(EQUIVALENT SOLID PLATE)

SECTION A-A

PERFORATED PLATE STRESS INTENSITY

$$S = K \frac{P}{h} \sigma_T = (1)(2.37)(6.5) = 15.4 \text{ KSI}$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-115 E-1
SHEET 7 OF 13
DATE 2-15-73 BY P. Anderson
CHECK DATE _____ BY _____

CHARGE NO. D-51100
DESCRIPTION EVAPORATOR H.P. TUBESHEET

STRESSES

TUBESHEET AT VESSEL WALL (SECTION B-B)

$$\text{THICKNESS} = t = 7.5 \text{ IN.}$$

$$\text{CENTROID} = r_c = \frac{t}{2} = 3.75 \text{ IN.}$$

TOTAL FORCE PER UNIT LENGTH

$$\begin{aligned} F &= \sum \sigma_i r_i \\ &= 1.5 (-3.0 - 1.38 + .27 + 2.42 + 6.84) \\ &= 7.73 \text{ KIPS/IN} \end{aligned}$$

MOMENT PER UNIT LENGTH

$$\begin{aligned} M &= \sum F_i d_i \\ &= -3.0(1.5)(3.) - 1.38(1.5)(1.5) + 2.42(1.5)(-1.5) \\ &\quad + 6.84(1.5)(-3.) \\ &= -52.83 \text{ IN-KIPS/IN} \end{aligned}$$

STRESSES

MEMBRANE $\sigma_M = F/t = 7.73/7.5 = 1.0 \text{ KSI}$

BENDING $\sigma_B = \pm 6M/t^2 = \pm \frac{6(-52.83)}{(7.5)^2} = \mp 5.6 \text{ KSI}$

$$\sigma_{\text{INSIDE}} = 1.0 - 5.6 = \underline{-4.6 \text{ KSI}}$$

$$\sigma_{\text{OUTSIDE}} = 1.0 + 5.6 = \underline{6.6 \text{ KSI}}$$

FIG. 5
30 MW EVAPORATOR
TUBESHEET AT VESSEL WALL

SECTION B-B

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 55-115 E-1SHEET 9 OF 13CHARGE NO. D-51100DATE 2-15-73 BY P. AndersonDESCRIPTION EVAPORATOR H.P. TUBESHEET

CHECK DATE _____ BY _____

STRESSESUPPER SHELL / TUBESHEET JUNCTURE (SECTION C-C)

$$\text{THICKNESS } t = .92 + 5(.8) = 4.92 \text{ IN}$$

$$\text{CENTROID } r_c = t/2 = 2.46 \text{ IN.}$$

TOTAL FORCE PER UNIT LENGTH

$$\begin{aligned} F &= \sum \sigma_i r_i \\ &= 13.8(.92) + .8(5.61 + 3.94 + 2.27 + .56 - 1.90) \\ &= 21.1 \text{ KIPS/IN} \end{aligned}$$

MOMENT PER UNIT LENGTH

$$\begin{aligned} M &= \sum F_i d_i \\ &= 13.8(.92)(2) + 5.61(.8)(1.14) + 3.94(.8)(.34) \\ &\quad + 2.27(.8)(-.46) + .56(.8)(-1.26) - 1.90(.8)(-2.06) \\ &= 33.3 \text{ IN-KIPS/IN} \end{aligned}$$

STRESSES

$$\text{MEMBRANE } \sigma_M = F/t = 21.1/4.92 = 4.3 \text{ KSI}$$

$$\text{BENDING } \sigma_B = \pm 6M/t^2 = \pm \frac{6(33.3)}{(4.92)^2} = \pm 8.3 \text{ KSI}$$

$$\sigma_{\text{INSIDE}} = 4.3 + 8.3 = \underline{12.6 \text{ KSI}}$$

$$\sigma_{\text{OUTSIDE}} = 4.3 - 8.3 = \underline{-4.0 \text{ KSI}}$$

FIG. 6

30 MWT EVAPORATOR
UPPER SHELL / TUBESHEET JUNCTION
MERIDIONAL STRESS

SECTION C-C

FIG. 7
30 MW EXAPORATOR
TIMESHEET / FLANGE JUNCTION
NORMAL STRESS
SECTION E-E

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-115 E-1SHEET 12 OF 13CHARGE NO. D-5100DATE 2-15-73 BY P. AndersonDESCRIPTION EVAPORATOR H.P. TUBE SHEET

CHECK DATE _____ BY _____

STRESSESUPPER SHELL TRANSITION (SECTION D-D)

THE MAXIMUM LONGITUDINAL STRESS OCCURS AT THE INSIDE SURFACE AND IS OBTAINED BY EXTRAPOLATING THE ELEMENT STRESSES TO THE BOUNDARY. FROM THE FINITE ELEMENT ANALYSIS, THE EXTRAPOLATED BOUNDARY STRESS IS

$$\sigma_z = 6.1 \text{ ksi}$$

IT SHOULD BE NOTED THAT THIS STRESS IS LESS THAN THE HOOP STRESS (σ_θ) OF 6.7 ksi FOR THE INNERMOST ELEMENT.

LOWER SHELL TRANSITION (SECTION F-F)

THE EXTRAPOLATED BOUNDARY STRESS AT SECTION F-F IS

$$\sigma_z = 1.6 \text{ ksi}$$

WHICH IS LESS THAN THE HOOP STRESS OF 2.1 ksi.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-115 E-1

SHEET 13 OF 13

CHARGE NO. D-51100

DATE 2-15-73 BY P. Anderson

DESCRIPTION EVAPORATOR H.P. TUBESHEET

CHECK DATE _____ BY _____

STRESS RESULTS

SECTION	S_m (ksi)	σ (ksi)	ALLOWABLE (ksi)	STRESS TYPE
A-A	19.1	15.4	$1.5 S_m = 28.6$	BEND.
B-B	19.1	6.6	$1.5 S_m = 28.6$	BEND.
C-C	19.1	12.6	$1.5 S_m = 28.6$	BEND.
D-D	16.2	6.7	$S_m = 16.2$	MEM.
E-E	19.1	-5.9	$1.5 S_m = 28.6$	BEND.
F-F	19.1	2.1	$S_m = 19.1$	MEM.

CHATTANOOGA DIVISION

TITLE

FOR THE EVAPORATOR

SS-100	E-2	January 31, 1973
CALCULATION NO.		DATED
D-51100		30 M.W. Demonstration Plant
CONTRACT NO.		UNIT DESIGNATION

J. M. Faircloth
PREPARED

CHECKED

REVIEWED

[illegible]

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-100 E-2SHEET 1 OF 17DATE 1-31-73 BY FAIRCLOTHCHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATIONCHECK DATE 1-31-73 BY TABLE OF CONTENTS

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-100 E-2SHEET 2 OF 17DATE 1-31-73 BY FairclothCHARGE NO. D-51100CHECK DATE 1-31-73 BY DESCRIPTION BASIC SIZING CALCULATION**I. ABSTRACT**

Presented in this calculation are the ASME code justifications for the basic dimensions of the evaporation side of the sodium to water steam generator for the 30 MW demonstration plant. The stresses considered are those resulting from design pressure and design temperature.

II. SIGNIFICANT RESULTS

All stresses are satisfactory and meet the appropriate allowables set forth in the ASME Boiler and Pressure Vessel Code, Section III, including all addenda through the Summer of 1971. For 304 and 316 stainless steels at design temperatures above 700°F the stress allowables given in A.S.M.E. Code Case 1331-5 are used. For the 2-1/4% chromium material at design temperatures above 700°F the stress allowable given in the ASME Boiler and Pressure Vessel Code, Section VIII are used.

The following is a summary of the pertinent stresses and dimensions determined in this analysis:

(See next page)

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. D-51100

DESCRIPTION BASIC SIZING CALCULATION

NUMBER SS-100 E-2

SHEET 3 OF 17

DATE 1-31-73 BY Faircloth

CHECK DATE 1-31-73 BY

Member		Stress Type	Stress (ksi) or Thick-ness(in)	Allowable or Actual	Reference Sheet No.
STEAM CHEST	Closure Head	Bending	19.6	28.1	6
	Closure Studs	Tension	24.6	26.3	7
	Sodium Tube Sheet	Bending	19.7	28.1	8
	Recirculation Inlet Nozzle	Reinforce-ment Area	10.4	12.4	12
	Vessel Wall Thickness	Membrane	3.1	4.0	7
	Inlet Nozzle Wall Thickness	Membrane	.50	.63	12
	Steam Outlet Nozzle	Reinforce-ment Area	10.4	12.4	13
INLET PLENUM	Closure Plate	Bending	19.9	24.3	15
	Plenum Wall Thickness	Membrane	.194	.624	15
	Nozzle Rein-forcement	Reinforce-ment Area	.618	1.174	16
	Tube Sheet	Bending	12.8	20.9	17

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-100 E-2SHEET 4 OF 17CHARGE NO. D-51100DATE 1-31-73 BY FairclothDESCRIPTION BASIC SIZING CALCULATIONCHECK DATE 1-31-73 BY III. GENERAL DISCUSSION

The evaporator side of the sodium to water steam generator takes the feedwater at temperature of 633.5°F and pressure of 2648 psia and heats it to a temperature of 675.5°F. The exit pressure is 2629 psia. The evaporator steam chest is designed for temperature of 675°F and a pressure of 2650 psia. The inlet plenum is conservative design for a differential pressure of 250 psia.

The feedwater flow rate of 338,000 lb/hr produces negligible flow loads.

IV. REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section III for Nuclear Vessels, including all addenda through the Summer 1971.
2. ASME Boiler and Pressure Vessel Code, Section VIII for Unfired Pressure Vessels.
24. ASME Boiler and Pressure Vessel Code, Section II, Material Specifications, Part A Ferrous.
57. Interpretations of the ASME Boiler and Pressure Vessel Code, Case 1331-5, August 4, 1971.

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATIONII. DETAILED ANALYSISA. EVAPORATOR STEAM CHEST1. GEOMETRY

DESIGN TEMPERATURE = 675 F
DESIGN PRESSURE = 2650 psia

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

IV DETAILED ANALYSIS

A. EVAPORATOR STEAM CHEST

2. CLOSURE HEAD

(MAT: SA-182-F22)

REF. 1 ARTICLE A-5000 "ANALYSIS OF FLAT CIRCULAR HEADS"

$$P = 2650 \text{ PSI}$$

$$t = 7.5''$$

$$\nu = .3$$

$$\sigma_r = P \frac{3}{8t^2} [(3+\nu)(R^2 - r^2)] = 2.65 \left(\frac{3}{8(7.5)^2} \right) [(3.3)(17.7085)^2]$$

$$\sigma_r = 18.3 \text{ ksi}$$

$$\sigma_i = -\frac{P}{2} = -\frac{2.65}{2} = -1.33 \text{ ksi}$$

STRESS INTENSITY

$$\sigma_r - \sigma_i = 19.6 \text{ ksi} < 1\frac{1}{2} S_M = 28.1 \text{ ksi @ } 675 \text{ F}$$

3. CLOSURE STUDS (MAT. SA-193-B7)

THE CLOSURE STUDS ARE TENTATIVE SIZED TO MEET THE GENERAL PRIMARY STRESS INTENSITY LIMIT OF PAR NB-3230 OF REF. 1

$$\text{BLOW OFF LOAD } L = \frac{\pi}{4} (35.417)^2 2.65 = 2610.7118 \text{ KIPS}$$

IT WILL BE ASSUMED THAT 1.5 KIPS PER INCH OF O-RING IS REQUIRED FOR SEATING

$$\text{SEATING LOAD, } SL = \pi (1.5) [32.827 + 35.417] = 321.5920 \text{ KIPS}$$

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

V. DETAILED ANALYSIS

A. EVAPORATOR STEAM CHEST

3. CLOSURE STUDS

TOTAL BOLT LOAD, $P = L + SL = 2932.3038 \text{ KIPS}$

BOLT AREA, $A = 24(2.5)^2(\pi/4) = 117.8096 \text{ IN}^2$

BOLT STRESS $\sigma = \frac{P}{A} = 24.9 \text{ KSI} < S_M = 26.3 \text{ KSI @ } 675 \text{ F}$

4. STEAM CHEST SHELL THICKNESS

MAT: SA-387 GR. D ANNEALED
 $S_M = 15.9 \text{ KSI @ } 675 \text{ F}$

REQUIRED THICKNESS IS

$$t_r = \frac{PR}{S_M - .5P} = \frac{2.65(17.0)}{15.9 - .5(26.5)} = \underline{\underline{3.09" < 4.0" \quad \text{O.K.}}}$$

5. SODIUM TUBE SHEET

THE SODIUM TUBE SHEET WILL BE DESIGNED TO WITHSTAND THE STEAM PRESSURE WHEN THERE IS A LOSS OF SODIUM PRESSURE.

FOR ANALYSIS CONSIDER THE ENTIRE PLATE TO BE PERFORATED.

$$\eta = \frac{\text{LIGAMENT WIDTH}}{\text{PITCH}} = \frac{2 - 1.156}{2} = .422$$

FROM FIG. A-8131-1 OF REF. 1

$$\hookrightarrow \frac{E^*}{E} = .4$$

$$\gamma^* = .32$$

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATIONV. DETAILED ANALYSISA. EVAPORATOR STEAM CHEST5. SODIUM TUBE SHEET

(MAT: SA-182 F22)

THIS TUBE SHEET IS SIZED ON THE BASIS OF A FINITE ELEMENT ANALYSIS OF A SIMILAR GEOMETRY.

THE FOLLOWING ARE THE RESULTS OF THE FINITE ELEMENT ANALYSIS:

BENDING STRESS AT THE CENTER OF THE PLATE

THIS STRESS IS IN THE PERFORATED REGION OF THE PLATE AND HENCE MUST BE MODIFIED.

$$S = K \frac{P}{h} \nabla_r = (1)(2.435)(6.75) = \underline{\underline{16.4 \text{ ksi}}}$$

THE FINITE ELEMENT ANALYSIS WAS PERFORMED ON GEOMETRY SIMILAR TO THE EVAPORATOR TUBE SHEET BUT NOT IDENTICAL. HENCE ACTUAL TUBE SHEET STRESS MUST BE EXTRAPOLATED.

CHARGE NO. D-51100DESCRIPTION BASIC SIZING CALCULATIONV. DETAILED ANALYSISA. EVAPORATOR STEAM CHEST5. SODIUM TUBE SHEET (CON'T)

THE BENDING STRESS IN THE PLATE IS A FUNCTION OF THE LOAD RADIUS AND THE PLATE THICKNESS

$$S = f(a^2/t^2)$$

FOR THE TUBE SHEET $(a/t)^2 = (17/7.5)^2 = 5.1378$

FOR FEM. ANALYSIS $(a/t)^2 = (28/13)^2 = 4.6391$
OF A SIMILAR TUBESHEET

HENCE $S = \frac{5.1378}{4.6391} (16.4) = 18.2 \text{ ksi}$

STRESS INTENSITY: $SI = 18.2 \text{ ksi} < 1/2 S_m = 28.1 \text{ ksi}$

BENDING STRESSES NEAR THE VESSEL WALL

$\sigma_r = \frac{5.1378}{4.6391} (6.0 \text{ ksi}) = \underline{\underline{6.6 \text{ ksi} < 1.55 S_m = 28.1 \text{ ksi}}}$

IV. DETAILED ANALYSISA. EVAPORATOR STEAM CHEST5. SODIUM TUBE SHEET (CON'T)

SHEAR THROUGH THE PLATE THICKNESS AT
OUTER MOST PENETRATION.

SHEAR STRESS τ_{xz}

$$\tau_{xz} = \frac{5.1378}{4.6391} (4.0) = 4.4 \text{ ksi}$$

$$= \underline{\underline{4.4 \text{ ksi} < .6 S_M = 11.3 \text{ ksi}}}$$

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

IV DETAILED ANALYSIS

A. EVAPORATOR STEAM CHEST

6. RECIRCULATION INLET NOZZLE

LIMITS OF REINFORCEMENT:

I. MEASURED ALONG THE VESSEL WALL IS

$$\frac{3}{2} [r + .5 \sqrt{rt}] = \frac{3}{2} [3.3125 + .5 \sqrt{19(4)}] = 11.5''$$

II. NORMAL TO THE VESSEL WALL

$$.5 \sqrt{r_m t_n} + .5 r_e = .5 \sqrt{(4.6563)(2.6875)} + .5 (1.125) = 2.3312''$$

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATIONIV. DETAILED ANALYSISA. EVAPORATOR STEAM CHEST6. RECIRCULATION INLET NOZZLEREQUIRED WALL THICKNESS

I. VESSEL WALL (MAT: SA-387-GRD ANNEALED)

$$t_r = \frac{PR}{S_M - .5P} = \frac{2.65(17)}{15.9 - .5(2.65)} = \underline{\underline{3.0909'' < 4.0''}}$$

II. NOZZLE WALL (MAT: SA-182-F22)

$$t_r = \frac{PR}{S_M - .5P} = \frac{2.65(3.3125)}{18.8 - .5(2.65)} = \underline{\underline{.5023'' < .625''}}$$

REQUIRED AREA OF REINFORCEMENT

$$A_r = (3.0909)(3.3125) + \left(\frac{3}{4}\right)^2 \left[1 - \frac{\pi}{4}\right] = \underline{\underline{10.3593 \text{ IN}^2}}$$

AREA AVAILABLE FOR REINFORCEMENT

$$A_A = A_1 + A_2 = .9091(7.6852) + (2.3312)(2.1852) + (1.125)^2 \left[1 - \frac{\pi}{4}\right]$$

$$\underline{\underline{A_A = 12.3524 \text{ IN}^2}}$$

A_A > A_r HENCE REINFORCEMENT IS ADEQUATE

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

V DETAILED ANALYSIS

A. EVAPORATOR STEAM CHEST

7. STEAM OUTLET NOZZLE

REQUIRED AREA OF REINFORCEMENT

$$A_R = \underline{\underline{10.3593 \text{ IN}^2}}$$

AREA AVAILABLE FOR REINFORCEMENT

$$A_A = A_1 + A_2 = \underline{\underline{12.3524 \text{ IN}^2}}$$

$$\underline{\underline{A_A > A_R \quad \text{HENCE REINFORCEMENT IS ADEQUATE}}}$$

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. D-51100

DESCRIPTION BASIC SIZING CALCULATION

NUMBER SS-100 E-2

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II DETAILED ANALYSIS

B. EVAPORATOR INLET PLENUM

1. GEOMETRY

DESIGN FOR AN INTERNAL PRESSURE = 250 PSIG

DESIGN TEMPERATURE = 650 F

FEED WATER FLOW RATE = 338,000 Lbs/hr

CHARGE NO. D-51100
DESCRIPTION BASK SIZING CALCULATION

V. DETAILED ANALYSIS

B. EVAPORATOR INLET PLENUM

2. CLOSURE PLATE

(MAT: SA-387 GR D)

REF. # 1 ARTICLE A-5000 "ANALYSIS OF FLAT CIRCULAR HEAD"

$$P = .25 \text{ KSI}$$

$$t = 1.75''$$

$$\gamma = .3$$

$$\sigma_r = P \frac{3}{8t^2} [(3 + \gamma) R^2] = .25 \left(\frac{3}{8(1.75)^2} \right) [(3.3)(14)^2] = 19.8 \text{ KSI}$$

$$\sigma_i = -\frac{P}{2} = .125 \text{ KSI}$$

STRESS INTENSITY:

$$\sigma_r - \sigma_i = 19.9 \text{ KSI} < 1\frac{1}{2} S_H = 24.3 \text{ KSI @ 650 F}$$

3. PLENUM WALL THICKNESS

(MAT: SA-387 GR. D)

$$t_r = \frac{PR}{S_m - .5P} = \frac{.25(12.5)}{16.2 - .5(.25)} = \underline{\underline{.194'' < .624'' \text{ O.K.}}}$$

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

V. DETAILED ANALYSIS

B. EVAPORATOR INLET PLENUM

4. NOZZLE OPENING

$$L = 3.1875$$

AREA REQUIRED: $A_R = .194(3.1875) = .618 \text{ in}^2$

AREA AVAILABLE: $A_A = .431(3.1875) = 1.374 \text{ in}^2$

SINCE $A_A > A_R$ REINFORCEMENT IS ADEQUATE

5. TUBE SHEET

(MAT: SA-240-405)

FROM FIG. A-8/31-1 OF REF. 1 FOR $\eta = .422$

$$E^*/E = .4 \quad \& \quad \gamma^* = .32$$

$$P = .25 \text{ ksi}$$

$$t = 3.0 \text{ in}$$

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

V. DETAILED ANALYSIS

B. EVAPORATOR INLET PLENUM

5. TUBE SHEET (CON'T)

$$\nabla_r = P \frac{3}{8L^2} [(3.17)(R^2)] = \frac{(25)(3)}{8(3)^2} [(3.32)(12.5)^2] = 5.4 \text{ KSI}$$

STRESS INTENSITY: (REF¹ FIG. A-8142-1)

$$SI = K \frac{P}{h} \nabla_r = \left(\frac{2}{.844}\right)(5.4) = 12.8 \text{ KSI}$$

$$\underline{\underline{SI = 12.8 \text{ KSI} < \frac{1}{2} S_m = \frac{1}{2}(13.9) = 20.9 \text{ KSI}}}$$

6. FLOW LOADS

$$\text{INLET FLOW} = 338,000 \text{ \#/hr}$$

$$F = \frac{d}{dt}(MV)$$

$$\text{WHERE: } M = \frac{338,000}{3600 \times 32.2} = 2.9158 \text{ SLUGS/SEC}$$

$$V = \frac{Q}{A} = \frac{(338,000)}{(39.3)(3600)\pi\left(\frac{2.8125}{12}\right)^2} = 13.8436 \text{ FT/SEC}$$

HENCE:

$$F = (2.9158)(13.8436) = \underline{\underline{40.4 \text{ \#/sec}}}$$

THIS IS A NEGLIGIBLE LOAD AND HENCE
WILL NO BE CONSIDERED FURTHER.

CHATTANOOGA DIVISION
NUCLEAR COMPONENTS DEPARTMENT

FOR THE SUPERHEATER

REVIEWED

[illegible]

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-105 E-2
SHEET 1 OF 15
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CHECK DATE _____ BY _____

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

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COMBUSTION ENGINEERING, INC.
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CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

I. ABSTRACT

Presented in this analysis are the ASME Code justifications for the basic dimensions of the superheater side of the sodium to water steam generator for the 30 MW demonstration plant. For cases where the metal temperature exceeds 700°F the stress allowables of the ASME Code Section VIII and ASME Code Case 1331-5 were used. The stresses considered are those resulting from design pressure and design temperature.

II. SIGNIFICANT RESULTS

All stresses are satisfactory and meet the appropriate allowables set forth in the ASME Boiler and Pressure Vessel Code, Section III including all addenda through the Summer of 1971. For 304 and 316 stainless steels at temperature above 700°F the stress allowables given in ASME Code Case 1331-5 are used. For the 2-1/4% chromium material at a design temperature above 700°F the stress allowables given in the ASME Boiler and Pressure Vessel Code Section VIII are used.

The following is a summary of the pertinent stresses and dimensions determined in this analysis:

(See next page)

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

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 DESCRIPTION BASIC SIZING CALCULATION

 NUMBER SS-105 E-2

 SHEET 3 OF 15

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Member		Stress Type	Stress (ksi) or Thickness (in)	Allowable or Actual	Reference Sheet No.
STEAM CHEST	Closure Head	Bending	18.0	28.1	6
	Closure Studs	Design Tension	21.9	26.3	7
	Vessel Wall Thickness	Membrane	2.4	3.5	7
	Sodium Tube Sheet	Bending	27.6	28.1	8
	Inlet Nozzle Wall Thickness	Membrane	.5	.63	8
	Steam Inlet Nozzle	Reinforcement Area	8.0	12.4	10
	Steam Outlet Nozzle	Reinforcement Area	8.0	11.9	11
OUT PLENUM	Closure Head	Bending	11.9	19.7	13
	Plenum Wall Thickness	Membrane	675.1	250	14
	Outlet Nozzle	Reinforcement Area	2.44	2.63	14
	Plenum Tube Sheet	Bending	6.1	19.7	15

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

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CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

III. GENERAL DISCUSSION

The superheater side of the sodium to water steam generator takes saturated steam at a temperature of 673.3°F and a pressure of 2589 psia and heats it to an outlet temperature of 906.1°F and a pressure of 2506.4 psia. The superheater steam chest and inlet nozzle is designed for a temperature of 675°F and a pressure of 2650 psia. The outlet plenum and outlet nozzle is designed for a temperature of 900°F and a pressure of 2510 psia.

IV. REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section III for Nuclear Vessels, including all addenda through the summer of 1971.
2. ASME Boiler and Pressure Vessel Code, Section VIII for Unfired Pressure Vessels.
24. ASME Boiler and Pressure Vessel Code, Section II Material Specification, Part A Ferrous.
57. Interpretations of the ASME Boiler and Pressure Vessel Code, Case 1331-5, August 4, 1971.

DESCRIPTION BASIC SIZING CALCULATIONIV. DETAILED ANALYSISA. SUPERHEATER STEAM CHEST1. GEOMETRY

DESIGN TEMPERATURE = 675 F
 DESIGN PRESSURE = 2650 PSI

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

V. DETAILED ANALYSIS

A. SUPERHEATER STEAM CHEST

2. CLOSURE HEAD

(MAT: SA-182 F22)

REF. 1 ARTICLE A-5000 "ANALYSIS OF FLAT CIRCULAR HEADS"

$$P = 2650 \text{ PSI}$$

$$t = 6\frac{1}{2}''$$

$$\gamma = .3$$

$$\sigma_r = P \frac{3}{8t^2} [(3+\gamma)(R^2-r^2)] = 2.65 \left(\frac{3}{8(6.5)^2} \right) [(3.3)(14.2085)^2]$$

$$\sigma_r = 15.7 \text{ ksi}$$

$$\sigma_t = -\frac{P}{2} = -\frac{2.65}{2} = -1.3 \text{ ksi}$$

STRESS INTENSITY:

$$\sigma_r - \sigma_t = 18.0 \text{ ksi} < 1\frac{1}{2} S_u = 28.1 \text{ ksi} @ 675 \text{ F}$$

3. CLOSURE STUDS (MAT: SA-193-B7)

THE CLOSURE STUDS ARE TENTATIVE SIZED TO MEET THE GENERAL PRIMARY STRESS INTENSITY LIMIT OF PAR. NB-3230 OF REF. 1

$$\text{BLOW OFF LOAD } L = \pi (14.2085)^2 2.65 = 1680.7064 \text{ kips}$$

IT WILL BE ASSUMED THAT 1.5 KIPS PER INCH OF O-RING IS REQUIRED FOR SEATING

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

V. DETAILED ANALYSIS

A. SUPERHEATER STEAM CHEST

3. CLOSURE STUDS

$$\text{O-RING SEATING LOAD, } SL = \pi(1.5)[25.827 + 28.417]$$

$$SL = 255.6186 \text{ KIPS}$$

$$\text{TOTAL BOLT LOAD} = L + SL = 1936.3250 \text{ KIPS}$$

$$\text{BOLT AREA (18-2\frac{1}{2}" \text{ STUDS}) } A = \frac{\pi}{4}(2.5)^2 18 = 88.3572 \text{ IN}^2$$

$$\text{BOLT STRESS, } \sigma = \frac{P}{A} = 21.9 \text{ KSI} < S_M = 26.3 \text{ KSI @ 675 F}$$

4. STEAM CHEST SHELL THICKNESS

MAT: SA-387 GR. D ANNEALED

$$S_M = 15.9 \text{ KSI @ 675 F}$$

THE REQUIRED THICKNESS IS

$$t_r = \frac{PR}{S_M - 0.5P} = \frac{2.65(13)}{15.9 - 0.5(2.65)} = \underline{\underline{2.3636 \text{ IN} < 3\frac{1}{2} \text{ O.K.}}}$$

5. SODIUM TUBE SHEET

THE SODIUM TUBE SHEET WILL BE DESIGNED TO WITHSTAND THE STEAM PRESSURE WHEN THERE IS A LOSS OF SODIUM PRESSURE

FOR ANALYSIS CONSIDER THE ENTIRE PLATE TO BE PERFORATED.

$$\eta = \frac{\text{LIGAMENT WIDTH}}{\text{PITCH}} = \frac{2 - 1.116}{2} = \underline{\underline{.442}}$$

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

V. DETAILED ANALYSIS

A. SUPERHEATER STEAM CHEST

S. SODIUM TUBE SHEET

FROM FIG. A-8131-1 OF REF. 1

$$E/E^* = .43 \quad \gamma^* = .31$$

$$P = 2650$$

$$t = 6\frac{3}{4}''$$

$$\gamma^* = .31$$

$$\sigma_r = P \left(\frac{3}{8t^2} \right) [(3+\gamma^*)(R^2-r^2)] = \frac{2.65(3)}{8(6.75)^2} [3.31(13)^2] = \underline{\underline{12.2 \text{ KSI}}}$$

STRESS INTENSITY

$$SI = K \frac{P}{h} \sigma_r = \frac{2}{.884} (12.2) = \underline{\underline{27.6 \text{ KSI} < 1\frac{1}{2} S_m = 28.1 \text{ KSI @ 675}}}$$

G. INLET NOZZLE - REQUIRED WALL THICKNESS (MAT: SA-182 F22)

DESIGN TEMPERATURE = 675 F

DESIGN PRESSURE = 2650 PSI

$$t_r = \frac{PR}{S_m - .5P} = \frac{2.65(3.3125)}{18.8 - .5(2.65)} = \underline{\underline{.5023 < .625''}}$$

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

V. DETAILED ANALYSIS

A. SUPERHEATER STEAM CHEST

7. STEAM INLET NOZZLE

REQUIRED AREA OF REINFORCEMENT

$$A_r = (3.3125)(2.3636) + \left(\frac{3}{4}\right)^2 \left[1 - \frac{\pi}{4}\right] = \underline{\underline{7.9501 \text{ IN}^2}}$$

LIMIT OF REINFORCEMENT

I. MEASURED ALONG THE VESSEL WALL:

$$\frac{3}{2} [r + .5\sqrt{rt}] = \frac{3}{2} [3.3125 + .5\sqrt{(13)(3.5)}] = \underline{\underline{10.03''}}$$

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CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

V. DETAILED ANALYSISA. SUPERHEATER STEAM CHEST7. STEAM INLET NOZZLELIMIT OF REINFORCEMENT (CON'T)II. MEASURED NORMAL TO THE VESSEL WALL

$$L = .5\sqrt{r_m t_n} + .5r_2 = .5\sqrt{(4.6563)(2.6875)} + .5(1.125)$$

$$L = 2.3312"$$

AREA AVAILABLE FOR REINFORCEMENT

$$A_A = A_1 + A_2 = (6.2152)(1.1364) + (2.1852)(2.3312) + (1.125)^2 \left[1 - \frac{\pi}{4}\right]$$

$$A_A = \underline{\underline{12.4287 \text{ IN}^2}}$$

$A_A > A_r$ HENCE THE REINFORCEMENT IS ADEQUATE

8. STEAM OUTLET NOZZLE

CHARGE NO. D-51100
DESCRIPTION BASIC SIZING CALCULATION

II. DETAILED ANALYSIS

A. SUPERHEATER STEAM CHEST

8. STEAM OUTLET NOZZLE

REQUIRED NOZZLE THICKNESS ($S_m = 14 \text{ KSI REF.}$)

$$t_r = \frac{PR}{S_m - .5P} = \frac{(2.51)(3.3125)}{14 - .5(2.51)} = \underline{\underline{.6524" < .75" \text{ O.K.}}}$$

LIMIT OF REINFORCEMENT

I. MEASURE ALONG THE VESSEL WALL:

$$L = 10.03" \text{ (SEE SHEET } \underline{\quad} \text{)}$$

II. MEASURE NORMAL TO THE VESSEL WALL

$$L = .5\sqrt{r_m t_n} + .5r_2 = 2.3312" \text{ (SEE SHEET } \underline{\quad} \text{)}$$

REQUIRED AREA OF REINFORCEMENT

$$A_R = (3.3125)(2.3636) + \left(\frac{3}{4}\right)^2 \left[1 - \frac{\pi}{4}\right] = \underline{\underline{7.9501 \text{ IN}^2}}$$

AREA AVAILABLE FOR REINFORCEMENT

$$A_A = A_1 + A_2 = (6.0651)(1.1364) + (2.0351)(2.3312) + (1.125)^2 \left[1 - \frac{\pi}{4}\right]$$

$$\underline{\underline{A_A = 11.9082 \text{ IN}^2}}$$

$A_A > A_R$ HENCE REINFORCEMENT IS ADEQUATE

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COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-105 E-2SHEET 12 OF 15DATE 1-31-73 BY FancherCHECK DATE 1-31-73 BYCHARGE NO. D-51100DESCRIPTION BASIC SIZING CALCULATIONV. DETAILED ANALYSISB. SUPERHEATER OUTLET PLENUM1. GEOMETRY

DESIGN FOR AN EXTERNAL PRESSURE = 250 PSIG

DESIGN TEMPERATURE = 900 F

CHARGE NO. D-S1100
DESCRIPTION BASIC SIZING CALCULATION

V. DETAILED ANALYSIS

B. SUPERHEATER OUTLET PLENUM

2. CLOSURE PLATE

(MAT: SA-387 GR.D)

REF. #1 ARTICLE A-5000 "ANALYSIS OF FLAT CIRCULAR PLATE"

$$P = .25 \text{ KSI}$$

$$t = 1.5"$$

$$\nu = .3$$

$$\sigma_r = P \frac{3}{8t^3} [(3+\nu)R^2] = .25 \frac{3}{8(1.5)^3} [(3.3)(9.25)^2] = 11.8 \text{ KSI}$$

$$\sigma_t = -\frac{P}{2} = -.125 \text{ KSI}$$

STRESS INTENSITY:

$$\sigma_r - \sigma_t = 11.8 + .125 = 11.9 \text{ KSI} < \frac{1}{2} S_y = 19.7 \text{ KSI @ 900F (REF. VIII)}$$

3. PLENUM WALL THICKNESS

REF. #1 PAR. NB-31133

$$D_o/t = 17.75/.75 = 23.7 > 10.0$$

MAT: SA-387 GR.D MIN. YIELD = 30 KSI

$$L/D_o = 14.75/34 = .43$$

V. DETAILED ANALYSIS

B. SUPERHEATER OUTLET PLENUM

3. PLENUM WALL THICKNESS

ALLOWABLE WORKING PRESSURE IS:

$$P_a = \frac{4B}{3D/E} = \frac{4B}{3(23.7)}$$

WHERE: 'B' IS TAKEN FROM FIG VII-1100-2

$$B = 12,000$$

$$P_a = \underline{675.1 \text{ PSI} > 250 \text{ PSI}} \quad \text{HENCE WALL THICKNESS} \\ \underline{\text{IS ADEQUATE}}$$

4. OUTLET NOZZLE REINFORCEMENT

$$\text{AREA REQUIRED, } A_R = (3/4)(3.25) = 2.44 \text{ IN}^2$$

$$\text{AREA AVAILABLE } A_a = 2(1.75)(.75) = 2.63 \text{ IN}^2$$

$$\underline{A_a > A_R \text{ HENCE REINFORCEMENT IS ADEQUATE}}$$

5. TUBESHEET

(MAT: SA-387 GR D)

FROM FIG. A-8131-1 OF REF*1 FOR $\eta = .442$

$$E/E^* = .43 \quad \& \quad \gamma^* = .31$$

CHARGE NO. D-51100DESCRIPTION BASIC SIZING CALCULATIONV. DETAILED ANALYSISB. SUPERHEATER OUTLET PLENUMS. TUBE SHEET (CON'T)

$$P = .25 \text{ KSI}$$

$$t = 2\frac{3}{4}''$$

$$\gamma = .31$$

$$\nabla_r = P \frac{3}{8t^2} [(3+\gamma)R^2] = \frac{.25(3)}{8(2.75)^2} [(3.31)(8.125)^2] = \underline{\underline{2.7 \text{ KSI}}}$$

STRESS INTENSITY:

$$SI = K \frac{P}{h} \nabla_r = \frac{2}{.884} (2.7) = 6.1 \text{ KSI}$$

$$\underline{\underline{SI = 6.1 \text{ KSI} < 1\frac{1}{2} S_M = 19.7 \text{ KSI @ 900 F (REF. VIII)}}$$

E-3

NUCLEAR COMPONENTS DEPARTMENT

PRELIMINARY STRUCTURAL ANALYSIS OF TUBE TO TUBESHEET WELD

W. J. Heilker
W. J. HEILKER
PREPARED

S.R. Penfield, Jr.
CHECKED

Handwritten signature
REVIEWED

E-3

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER E-3
SHEET 1 OF 24
DATE 1-31-73 BY HEILKER
CHECK DATE 1-31-73 BY SEP

CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD

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NUMBER E-2

SHEET 2 OF 24

DATE 1-31-73 BY HEILKER

CHECK DATE 1-31-73 BY SP

CHARGE NO. _____

DESCRIPTION TUBE TO TUBESHEET WELD

1. ABSTRACT

This analysis presents the preliminary structural evaluation of the pressure tube to high pressure tubesheet weld. Stresses considered are those resulting for steam side design pressure, sodium side pressure, and forced displacement of the tubeweld due to tubesheet deflection under design loading.

The analysis is made in accordance with the 1971 ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Plant Components and includes Addenda through Summer, 1972.

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CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD

2. SIGNIFICANT RESULTS

All stresses are satisfactory and meet the appropriate allowables set forth in the ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Plant Components.

The highest value of local primary membrane stress intensity occurred at Cut 5-6 (See sheet 18). The stress intensity was 20.4 ksi which did not exceed the allowable of $1.5 S_m = 22.2$ ksi.

The greatest range of primary local plus secondary stress intensity (for pressure and forced displacement only) was 26.4 ksi which was well below the allowable of $3 S_m = 44.4$ ksi. This value occurred at Location 5 (See sheet 18). The effects of temperature on the range of stress will be considered in the fatigue evaluation.

CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD

3. GENERAL DISCUSSION

The forced displacement imposed upon the tubeweld was determined by modeling the tubesheet, sodium flange, high pressure shell, sodium shell, and support skirt (See sheet 9) with the "SAAS" Finite Element Computer Program (Reference 46) and extracting deflections in the area of the weld.

The above deflections together with steam side and sodium side pressure were loaded on the tubeweld model (See sheet 10) and evaluated with Wilson's Finite Element Computer Program (Reference 25).

The exaggerated deformed shapes shown on Sheets 14 and 15 give a qualitative representation of the type of stress (compressive or tensile) in various areas of the tubesheet and tubeweld. The iso-stress plots on Sheets 16 and 17 show the stress patterns that have formed in the tube to tubesheet weld.

Examination of the surface stresses tabulated on Sheet 19 will disclose that some surface yielding occurs, however, these areas will shake-down to elastic action after one cycle of loading.

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NUMBER E-3
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CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD

4. REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Plant Components.
25. Computer program, "Analysis of Axisymmetric Solids," E. L. Wilson, University of California, February, 1967.
46. "SAAS II Finite Element Stress Analysis of Axisymmetric Solids with Orthotropic, Temperature-Dependent Material Properties," by Robert M. Jones and James G. Crose, September, 1968.
48. "Giant (Graphical Information Analysis Tool)," Computer program, by J. J. Diorio and S. E. Deabler, Combustion Engineering.

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NUMBER 5-3

SHEET 6 OF 24

CHARGE NO. _____

DATE 10-4-72 BY HEILKER

DESCRIPTION TUBE TO TUBESHEET WELD

CHECK DATE 1-31-73 BY SRP

5. DETAILED ANALYSIS

a. GEOMETRY

MATERIAL

BASE METAL
2 1/4 Cr-1 Mo
SA-182 F-22

CLAD
9 Cr-1 Mo

TUBE
9 Cr-1 Mo
SA-213 T-9

CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD

5. DETAILED ANALYSIS

a. GEOMETRY

HOLE PATTERN IN TUBESHEET

$$R' = P - \frac{1}{4}(P-h) = P - \frac{r}{2}$$

WHERE : $P = 2.0 \text{ IN.}$
 $h = 0.844 \text{ IN.}$
 $r = 0.578 \text{ IN.}$

$$R' = 2.0 - \frac{0.578}{2} = 1.711 \text{ IN.}$$

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NUMBER E-3

SHEET 8 OF 24

DATE 1-18-73 BY HEILKEF

CHECK DATE 1-31-73 BY MP

CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD

5. DETAILED ANALYSIS

b. SYSTEM ALLOWABLES

1. THE LOCAL PRIMARY MEMBRANE STRESS INTENSITY DUE TO PRESSURE AND FORCED DISPLACEMENT, SHALL BE LESS THAN $1.5 S_m$ AT DESIGN TEMPERATURE.
2. THE PRIMARY PLUS SECONDARY STRESS INTENSITY RANGE SHALL BE LESS THAN $3 S_m$.

c. SYSTEM LOADING

1. DESIGN CONDITIONS AS FOLLOWS:
STEAM PRESSURE = 2650 PSI
SODIUM SIDE PRESSURE = 80 PSI } @ 675°F
2. FORCED DISPLACEMENT OF THE TUBEWELD DUE TO TUBESHEET DEFLECTION UNDER DESIGN LOADING (TUBEWELD ASSUMED TO BE AT THE CENTER OF THE TUBESHEET WHERE DEFLECTION IS MAXIMUM).

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SHEET 9 OF 24

DATE 12-1-72 BY HEILKER

CHECK DATE 1-31-73 BY MB

CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD

5. DETAILED ANALYSIS

d. MODEL

LOCATION
OF
TUBE WELD
ENLARGEMENT

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ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 7 2

SHEET 10 OF 24

CHARGE NO. _____

DATE 12-1-72 BY HEILKER

CHECK DATE 1-31-73 BY SP

DESCRIPTION TUBE TO TUBESHEET WELD

5. DETAILED ANALYSIS

d. MODEL

TUBEWELD

ENLARGEMENT

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-2SHEET 11 OF 24DATE 1-23-73 BY HEILKERCHECK DATE 1-31-73 BY SMCHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD5.) DETAILED ANALYSISB. FINITE ELEMENT ANALYSISMETHOD

IN ORDER TO DETERMINE THE STRESS IN THE TUBEWELD, IT IS FIRST NECESSARY TO CALCULATE THE AMOUNT OF DEFORMATION IMPOSED ON THE WELD BY THE FLEXING OF THE TUBESHEET. THIS WAS ACCOMPLISHED BY CONSTRUCTING A FINITE ELEMENT MODEL ENCOMPASSING THE TUBESHEET, SODIUM FLANGE, SODIUM SHELL, SUPPORT SKIRT, HIGH PRESSURE SHELL, STUDS AND NUTS. ONE ELEMENT OF THIS MODEL REPRESENTS THE TUBEWELD GEOMETRY SHOWN IN 5.A. THE MODEL WAS ANALYZED USING THE COMPUTER PROGRAM SAAS II, REFERENCE 46.

THE NEXT STEP WAS TO CONSTRUCT A DETAILED MODEL OF THE TUBEWELD. AS PART OF THE BOUNDARY CONDITIONS FOR THIS DETAILED MODEL, DEFLECTIONS WERE EXTRACTED FROM THE TUBESHEET MODEL. THE TUBEWELD MODEL WAS THEN ANALYZED USING "WILSON'S" FINITE ELEMENT COMPUTER PROGRAM REFERENCE 25.

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NUMBER E-3

SHEET 12 OF 24

CHARGE NO. _____

DATE 1-23-73 BY HEILKER

DESCRIPTION TUBE TO TUBESHEET WELD

CHECK DATE 1-31-73 BY MP

S. DETAILED ANALYSIS

C. FINITE ELEMENT ANALYSIS

TUBEWELD FORCED DISPLACEMENT

THE STRETCHING AND BENDING
OF THE TUBESHEET LOADED
WITH DESIGN PRESSURES, CAUSE
THE ABOVE FORCED DISPLACE-
MENTS OF THE TUBEWELD.

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NUMBER 5-2

SHEET 13 OF 24

DATE 1-24-73 BY HEILKER

CHECK DATE 1-31-73 BY MA

CHARGE NO. _____

DESCRIPTION TUBE TO TUBESHEET WELD

5.) DETAILED ANALYSIS

C. FINITE ELEMENT ANALYSIS

MATERIAL PROPERTIES

2 1/4 Cr - 1 Mo

DESIGN TEMPERATURE = 675°F

$E = 25.2 \times 10^6 \text{ PSI}$

$\nu = 0.3$

9 Cr - 1 Mo

DESIGN TEMPERATURE = 675°F

$E = 27.1 \times 10^6 \text{ PSI}$

$\nu = 0.3$

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NUMBER 5-3

SHEET 14 OF 24

CHARGE NO. _____

DATE 12-1-72 BY HEILKER

DESCRIPTION TUBE TO TUBESHEET WELD

CHECK DATE 1-31-73 BY SM

5.) DETAILED ANALYSIS

A. GRAPHICAL OUTPUT

DEFORMED SHAPE

EXAGGERATED.

STEAM PRESSURE = 2650 PSI

SODIUM SIDE PRESS. = 80 PSI

LOCATION OF
TUBEWELD
ENLARGEMENT

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NUMBER 5-3
SHEET 15 OF 24
DATE 12-1-72 BY HEILKER
CHECK DATE 1-31-73 BY CH

CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD

5.) DETAILED ANAL.

P. GRAPHICAL

OUTPUT

DEFORMED

SHAPE

EXAGGERATED

2650 PSI

80 PSI

SODIUM STEAM GENERATOR
EVAPORATOR
TUBEWELD
FULL POWER STEADY STATE
SIGMA Z

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. _____

DESCRIPTION TUBE TO TUBESHEET WELD

NUMBER E-3

SHEET 16 OF 24

DATE 1-17-73 BY HEILKER

CHECK DATE 1-31-73 BY SP

S.) DETAILED ANALYSIS

F. GRAPHICAL OUTPUT

SODIUM STEAM GENERATOR
EVAPORATOR
TUBEWELD
FULL POWER STEADY STATE
SIGMA T

COMBUSTION ENGINEERING, INC.
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CHARGE NO. _____

DESCRIPTION TUBE TO TUBESHEET WELD

NUMBER E-3

SHEET 17 OF 24

DATE 1-17-73 BY HEILKER

CHECK DATE 1-21-73 BY 40

5.) DETAILED ANALYSIS

A. GRAPHICAL OUTPUT

E-3

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NUMBER E-3

SHEET 18 OF 24

CHARGE NO. _____

DATE 1-30-73 BY HEILKER

CHECK DATE 1-31-73 BY SMP

DESCRIPTION TUBE TO TUBESHEET WELD

5.) DETAILED ANALYSIS

g. STRESSES

1. STRESS LOCATIONS

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NUMBER 5.5

SHEET 19 OF 24

CHARGE NO. _____

DATE 1-31-73 BY HEILKER

DESCRIPTION TUBE TO TUBESHEET WELD

CHECK DATE 1-31-73 BY WAB

5.) DETAILED ANALYSIS

g. STRESSES

2. SUMMARY

SURFACE STRESSES

INSIDE			OUTSIDE		
LOCATION	σ_{NORMAL}	σ_{θ}	LOCATION	σ_{NORMAL}	σ_{θ}
(1)	5.06	9.51	(2)	2.63	6.49
(3)	6.95	11.30	(4)	-1.02	5.61
(5)	-5.50	21.20	(6)	16.80	19.00
(7)	0.37	26.00	(8)	24.00	22.20

UNCONCENTRATED STRESS

LOCATION	INSIDE		MID-SURFACE		OUTSIDE	
	σ_{NORM}	σ_{θ}	σ_{NORM}	σ_{θ}	σ_{NORM}	σ_{θ}
(1)-(2)	4.77	9.43	3.76	7.81	2.75	6.19
(3)-(4)	6.66	10.99	2.93	8.20	-0.80	5.41
(5)-(6)	-6.26	20.09	3.51	19.01	13.29	17.93

CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD5.) DETAILED ANALYSIS9. STRESSES3. CALCULATIONSUNCONCENTRATED STRESS

STRESSES OBTAINED FROM THE FINITE ELEMENT ANALYSIS INCLUDE THE EFFECT OF STRESS CONCENTRATION. IN ORDER TO CALCULATE PRIMARY LOCAL MEMBRANE STRESS AND SECONDARY BENDING STRESS, IT IS NECESSARY TO REMOVE STRESS CONCENTRATION. THE METHOD DESCRIBED BELOW WAS USED TO DETERMINE THE UNCONCENTRATED STRESSES.

F = TOTAL FORCE ACTING NORMAL TO CUT.

$$F = \sum_{i=1}^n \sigma_i A_i$$

WHERE: σ_i = ELEMENT STRESS NORMAL TO CUT

A_i = ELEMENT AREA AT CUT

n = NUMBER OF ELEMENTS AT CUT

M = TOTAL BENDING MOMENT ACTING ON CUT.

$$M = \sum_{i=1}^n \sigma_i A_i d_i$$

WHERE: d_i = DISTANCE FROM $\bar{E}$ OF CUT TO CENTROID OF ELEMENT

USING THE TOTAL MOMENT AND TOTAL NORMAL FORCE ON THE CUT, THE UNCONCENTRATED STRESSES ARE CALCULATED.

$$\bar{\sigma} = \frac{F}{t} + \frac{6M}{t^2}$$

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CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD

5.) DETAILED ANALYSIS

9. STRESSES

3. CALCULATIONS

UNCONCENTRATED STRESS

EXAMPLE : (3) — (4)

ELEMENT	V_N	V_{NA}	V_{NAd}	V_θ	$V_{\theta A}$	$V_{\theta Ad}$
66	6.11	0.277	0.025	10.61	0.482	0.044
67	4.44	0.202	0.009	9.23	0.419	0.019
68	2.90	0.132	0	8.05	0.365	0
69	1.38	0.063	-0.003	7.02	0.319	-0.014
70	-0.22	-0.010	0.001	6.08	0.276	-0.025
$\Sigma =$		0.664	0.032	$\Sigma =$	1.861	0.024
		F	M		F $_\theta$	M $_\theta$

ASSUME UNIT THICKNESS

THICKNESS
 $t = 0.227$

$$V_N \text{ UNCONC.} = \frac{F}{t} \pm \frac{6M}{t^2} = 2.93 \pm 3.73 = 6.66 \text{ (3) INSIDE}$$

$$= -0.80 \text{ (4) OUTSIDE}$$

$$V_\theta \text{ UNCONC.} = \frac{F_\theta}{t} \pm \frac{6M_\theta}{t^2} = 8.20 \pm 2.79 = 10.99 \text{ (3) INSIDE}$$

$$5.41 \text{ (4) OUTSIDE}$$

CHARGE NO. _____
DESCRIPTION TUBE TO TUBESHEET WELD

5.) DETAILED ANALYSIS

9. STRESSES

3. CALCULATIONS

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NUMBER E-2

SHEET 23 OF 24

CHARGE NO. _____

DATE 1-31-73 BY HEILKER

DESCRIPTION TUBE TO TUBESHEET WELD

CHECK DATE 1-31-73 BY SP

5.) DETAILED ANALYSIS

h. RESULTS

CRITERION 5.b.1

PRIMARY LOCAL MEMBRANE

LOCATION	V_N	V_θ	V_r	STRESS INTENSITY		
				$V_N - V_\theta$	$V_N - V_r$	$V_\theta - V_r$
(1) — (2)	3.76	7.81	-1.37	-4.05	5.13	9.18
(3) — (4)	2.93	8.20	-1.37	-5.27	4.30	9.57
(5) — (6)	3.51	19.01	-1.37	-15.50	4.88	20.38

$$S.I. \text{ MAX} = \underline{20.38 \text{ KSI}} < 1.5 S_m = 22.2 \text{ KSI} @ 675^\circ F$$

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CHARGE NO. _____

NUMBER 5-2

SHEET 24 OF 24

DATE 1-31-73 BY HEILKER

CHECK DATE 1-31-73 BY SAP

DESCRIPTION TUBE TO TUBESHEET WELD

5.) DETAILED ANALYSIS

h. RESULTS

CRITERION 5.b.2

PRIMARY LOCAL PLUS SECONDARY

LOCATION	V_N	V_θ	V_P	STRESS INTENSITY		
				$V_N - V_\theta$	$V_N - V_P$	$V_\theta - V_P$
①	4.77	9.43	-2.65	-4.66	7.42	12.08
②	2.75	6.19	-0.08	-3.44	2.83	6.27
③	6.66	10.99	-2.65	-4.33	9.31	13.64
④	-0.80	5.41	-0.08	-6.21	-0.72	5.49
⑤	-6.26	20.09	-2.65	-26.35	-3.61	22.74
⑥	13.29	17.93	-0.08	-4.64	13.37	18.01

THE OPPOSING EXTREME FOR PURPOSES OF RANGE OF STRESS IS AMBIENT CONDITIONS WHERE ALL STRESS IS ZERO.

$$RANGE_{MAX} = 0 - (-26.35) = 26.35 \text{ KSI} < 3S_m = 44.4 \text{ KSI}$$

@ 675°F

REPORT NO. _____

TITLE

<i>E-4</i>	December 12, 1972
CALCULATION NO	DATED
D-51100	SODIUM S.G.
CONTRACT NO.	UNIT DESIGNATION

W. J. Giller
PREPARED

CHECKED

REVIEWED

[illegible]

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ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER E-4

SHEET 1 OF 20

DATE 2-9-73 BY HEILKER

CHARGE NO. D-51100

DESCRIPTION PRESSURE TUBE AT SODIUM-
ARGON INTERFACE

CHECK DATE _____ BY _____

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CHECK DATE _____ BY _____

CHARGE NO. _____

DESCRIPTION PRESSURE TUBE AT SODIUM-
ARGON INTERFACESUMMARY

The purpose of this analysis is to examine the high pressure tube at the sodium level in the steam generator, and determine if any inelastic deformation occurs. It is shown in this report that inelastic deformation does occur (See Sheet 14), and an attempt was made to calculate the incremental plastic strain using a simplified conservative method, the full relaxation Bree method. The Bree method proved, however, to be too conservative and the recommendation of this report is to perform a more rigorous inelastic calculation.

RESULTS

The stresses obtained from a seal-shell analysis (Sheet 7 through 10) indicate that the critical stress intensity is $\nabla_{\theta} - \nabla_{\alpha}$ on the inside surface of the tube. Two locations were examined in detail, Node 14, the location of maximum thermal cycling between steady level and fluctuating level, and Node 22, the location of maximum stress. The effects of fatigue and secondary creep were found to be small but plastic deformation was shown to exist. Although satisfactory results were not obtained using the full relaxation Bree method, it should be pointed out that this method assumes ratcheting to exist while the figure on Sheet 14 clearly indicates the stresses to be in the shakedown regime.

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NUMBER E-4

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DATE 2-9-73 BY HEILKER

CHECK DATE _____ BY _____

CHARGE NO. D-51100

DESCRIPTION PRESSURE TUBE AT SODIUM-
ARGON INTERFACE

REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Plant Components
2. Interpretations of ASME Boiler and Pressure Vessel Code, Case 1331-5, August 4, 1971.
3. Commitments and Agreements of Steam Generator Design Transients Meeting held at LMEC, November 15, 1972.
4. "Metals Handbook," Volume 1, Properties and Selection, Eighth Edition, American Society for Metals.
5. "Elastic-Plastic Behavior of Thin Tubes Subjected to Internal Pressure and Intermittent High-Heat Fluxes with Application to Fast-Nuclear-Reactor Fuel Elements," by J. Bree.
6. "Seal-Shell-2, A Computer Program for the Stress Analysis of a Thick Shell of Revolution with Axisymmetric Pressure, Temperature and Distributed Loads," WAPD-TM-398, AEC Research and Development Report, 1963.

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CHARGE NO. 0-51100

NUMBER E-4

SHEET 4 OF 20

DATE 12-12-72 BY HEILKER

DESCRIPTION PRESSURE TUBE AT SODIUM - ARGON INTERFACE

CHECK DATE _____ BY _____

GEOMETRY

IT IS ASSUMED THAT DURING NORMAL OPERATION OF THE SODIUM HEATED STEAM GENERATOR, THERE WILL BE PERIODS WHEN THE SODIUM LEVEL AT THE SODIUM - ARGON INTERFACE WILL BE STEADY. IT IS ALSO ASSUMED THAT THERE WILL BE PERIODS WHEN THE SODIUM LEVEL IS FLUCTUATING AT SOME RATE. IT IS THEN NECESSARY TO SHOW THAT THE PRESSURE TUBE IS NOT OVERSTRESSED BY CYCLING BETWEEN THESE CONDITIONS. ASSUME 30,000 CYCLES OR APPROXIMATELY ONE CYCLE/8 HOURS. ASSUME 600 CYCLES OF NORMAL STARTUP.

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DESCRIPTION PRESSURE TUBE AT SODIUM-
ARGON INTERFACE

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SHEET 5 OF 20

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CHECK DATE _____ BY _____

SEAL-SHELL MODEL (SEE REF. 6)

NODE	RADIUS	ELEVATION	THICKNESS
0	0.664	2.25	0.172
36	0.664	-2.25	0.172

BLOWOFF LOAD = 1.050 ΔP

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NUMBER E-4

SHEET 6 OF 20

DATE 12-12-72 BY HEILKER

CHECK DATE _____ BY _____

CHARGE NO. D-51100

DESCRIPTION PRESSURE TUBE AT SODIUM -
ARGON INTERFACE

LOADING

PRESSURE

FOR THE PURPOSES OF THIS ANALYSIS THE
NORMAL OPERATING PRESSURES ARE
COMBINED WITH THE THERMAL LOADINGS.
THE PRESSURES USED ARE AS FOLLOWS:

STEAM PRESSURE = 2650 PSI

SODIUM PRESSURE = 80 PSI

THERMAL

TEMPERATURE DATA IS TAKEN DIRECTLY
FROM C.E. CALCULATION "HIGH PRESSURE
TUBE SODIUM INTERFACE" DATED 11-2-72
BY DOUG SILVER WHICH APPEARED IN THE
NOVEMBER 1972 PROGRESS REPORT.

CONDITION A - STEADY LEVEL

CONDITION B - FLUCTUATING LEVEL

IT WAS FOUND THAT AFTER A NUMBER OF
FLUCTUATION, A STEADY TEMPERATURE
DISTRIBUTION IS FORMED. REGARDLESS OF
THE FREQUENCY OF FLUCTUATION, THE SAME
TEMPERATURE DISTRIBUTION IS FORMED.

CONDITION C - AMBIENT (ZERO STRESS)

STRESS (KSI)

25

20

15

10

5

FLUCTUATING
LEVEL

STEADY LEVEL

T_x STEAM SIDE (INSIDE)
AXIAL STRESS

PRESSURE TUBE
AT SODIUM - ARGON
INTERFACE 7 OF 20
12-11-72 HEILKER

2.0

1.0

0

-1.0

-2.0

HEIGHT ABOVE STEADY LEVEL

E-4

PRESSURE TUBE
AT SODIUM - ARGON
INTERFACE 9 OF 20
12-11-72 HEILKER

T_x SODIUM SIDE (OUTSIDE)
AXIAL STRESS

STRESS (KSI)

HEIGHT ABOVE STEADY LEVEL

10

5

0

2.0

1.0

0

-1.0

-2.0

-5

-10

STEADY LEVEL

FLUCTUATING
LEVEL

PRESSURE TUBE
AT SODIUM-ARGON
INTERFACE 10 OF 20
12-11-72 HELLKER

V₀ SODIUM SIDE (OUTSIDE)
CIRCUMFERENTIAL STRESS

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NUMBER E-4SHEET 11 OF 20DATE 12-13-72 BY HEILKER

CHARGE NO. D-51106
 DESCRIPTION PRESSURE TUBE AT SODIUM-
 ARGON INTERFACE

CHECK DATE _____ BY _____

PRIMARY STRESS (LOAD CONTROLLED)

ASSUME A DESIGN PRESSURE OF 2700 PSI @ 868°F

$$\tau_x = \frac{b^2 P}{2 R t} = 1.46 P = 3.94 \text{ KSI}$$

$$\tau_\theta = \frac{b P}{t} = 3.36 P = 9.07 \text{ KSI}$$

$$\tau_r = -\frac{P}{2} = -0.50 P = -1.35 \text{ KSI}$$

$$S.I. \text{ MAX} = \tau_\theta - \tau_r = 9.07 - (-1.35) = \underline{10.42 \text{ KSI}}$$

FROM SEC. VIII, ALLOWABLE $S = \underline{12.3 \text{ KSI}}$ @ 868°F

PRIMARY + SECONDARY STRESS

FOR THE CONSIDERATION OF SECONDARY STRESSES, TWO LOCATIONS WILL BE EXAMINED, NODE 14 AND NODE 22 (SEE SHEET 5). EXAMINATION OF THE STRESS CURVES ON THE PRECEDING SHEET REVEALS THAT THE CRITICAL STRESS INTENSITY IS $(\tau_\theta - \tau_r)$ ON THE INSIDE SURFACE OF THE TUBE.

NODE 14 - LOCATION OF MAXIMUM RANGE OF SECONDARY STRESS BETWEEN CONDITION A AND CONDITION B.

NODE 22 - LOCATION OF MAXIMUM RANGE OF SECONDARY STRESS.

NOTE THAT THE PRIMARY STRESS IS THE SAME AT ALL LOCATIONS. $(P_L + P_B/K) = P_m$

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NUMBER E-4SHEET 12 OF 20CHARGE NO. D-51100DATE 2-2-73 BY HEILKERDESCRIPTION PRESSURE TUBE AT SODIUM -
ARGON INTERFACE

CHECK DATE _____ BY _____

PRIMARY + SECONDARY STRESS CONT'DNODE 14 (INSIDE)CONDITION A - STEADY

$$T_m = 674^\circ F$$

$$S_y = 22.2 \text{ KSI}$$

$$V_\theta = 10.2 \text{ KSI}$$

$$S.I. = V_\theta - V_n = 12.85 \text{ KSI}$$

$$V_m = 3.36 (2.57) + 2.65$$

$$= 11.29 \text{ KSI}$$

$$V_T = 1.56 \text{ KSI}$$

CONDITION B - FLUCT.

$$T_m = 734^\circ F$$

$$S_y = 21.8 \text{ KSI}$$

$$V_\theta = 23.0 \text{ KSI}$$

$$S.I. = V_\theta - V_n = 25.65 \text{ KSI}$$

$$V_m = 11.29 \text{ KSI}$$

$$V_T = 14.36$$

CONDITION C - AMBIENT

$$V = 0$$

$$\left[\left(P_L + \frac{P_b}{K} \right)_{\text{MAX}} + Q_{\text{RANGE}} \right] \leq S_g$$

$$(V_{m \text{ MAX}} + V_{T \text{ RANGE}}) \leq S_{y \text{ AVG.}}$$

$$(11.29 + 14.36) \leq 22.0$$

$$\text{BUT } \underline{25.65} > 22.0$$

THUS INELASTIC
ANALYSIS IS REQUIREDFOR CONDITION B

$$x = V_m / V_y = 0.518$$

$$y = V_T / V_y = 0.659$$

(SEE SHEET 14)

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NUMBER E-4SHEET 13 OF 20CHARGE NO. D-51100DATE 2-2-73 BY HEILKERDESCRIPTION PRESSURE TUBE AT SODIUM -
ARGON INTERFACE

CHECK DATE _____ BY _____

PRIMARY + SECONDARY STRESS CONT'DNODE 22 (INSIDE)CONDITION A - STEADYCONDITION B - FLUCT.

$$T_m = 734^\circ F$$

$$T_m = 759^\circ F$$

$$S_y = 21.8 \text{ KSI}$$

$$S_y = 21.6 \text{ KSI}$$

$$V_\theta = 23.0 \text{ KSI}$$

$$V_\theta = 27.9 \text{ KSI}$$

$$S.I. = V_\theta - V_n = 25.65 \text{ KSI}$$

$$S.I. = V_\theta - V_n = 30.55 \text{ KSI}$$

$$V_m = 11.29 \text{ KSI}$$

$$V_m = 11.29 \text{ KSI}$$

$$V_T = 14.36 \text{ KSI}$$

$$V_T = 19.26 \text{ KSI}$$

CONDITION C - AMBIENT

$$V = 0$$

$$\left[\left(P_L + \frac{P_R}{K} \right)_{\text{MAX}} + Q_{\text{RANGE}} \right] \leq S_g$$

$$(V_{m \text{ MAX}} + V_{T \text{ RANGE}}) \leq S_{Y \text{ AVG}}$$

$$(11.29 + 19.26) \leq 21.7$$

$$\text{BUT } 30.55 > 21.7$$

THUS INELASTIC
ANALYSIS IS REQUIREDFOR CONDITION B

$$X = \frac{V_m}{V_y} = 0.523$$

$$Y = \frac{V_T}{V_y} = 0.892 \quad (\text{SEE SHEET } \underline{14})$$

CHARGE NO. D-51100
DESCRIPTION PRESSURE TUBE AT SODIUM-
ARGON INTERFACE

STRESS REGIMES FOR ONE-DIMENSIONAL
ELASTIC-PERFECTLY-PLASTIC MODEL

CHARGE NO. D-51100
DESCRIPTION PRESSURE TUBE AT SODIUM-
ARGON INTERFACE

FULL RELAXATION BREE METHOD

IN THE FULL RELAXATION BREE METHOD, IT IS ASSUMED THAT SUFFICIENT CREEP STRAINS OCCUR, WHILE THE WALL IS SUBJECT TO THE MAXIMUM THERMAL GRADIENT, TO RELAX THE STRESSES TO $\bar{\sigma}_m$ THROUGHOUT THE WALL. NO RELAXATION TAKES PLACE IN ANY OTHER PART OF THE CYCLE. USING THIS METHOD, RATCHETING OCCURS IN ALL REGIONS, SHOWN IN THE FIGURE ON SHEET 14, EXCEPT THE ELASTIC REGIME. THIS METHOD GIVES CONSERVATIVE PREDICTIONS RELATIVE TO THE MORE RIGOROUS INELASTIC METHODS OF ANALYSIS.

THE PLASTIC STRAIN INCREMENT PER CYCLE = ϵ_g

$$\epsilon_g = \frac{\bar{\sigma}_Y}{E} \delta \quad \text{WHERE } E = 24.6 \times 10^3 \text{ KSI @ } 750^\circ \text{F}$$

$$X = \bar{\sigma}_m / \bar{\sigma}_Y$$

$$Y = \bar{\sigma}_T / \bar{\sigma}_Y$$

$$\delta = 1 - X + Y - 2[Y(1-X)]^{1/2} \quad \text{FOR } (X, Y) \text{ IN } S_1$$

SEE SHEET 14

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NUMBER E-4SHEET 16 OF 20DATE 2-2-73 BY HEILKERCHARGE NO. D-51100

CHECK DATE _____ BY _____

DESCRIPTION PRESSURE TUBE AT SODIUM-ARGON INTERFACEFULL RELAXATION BREE METHOD CONT'DNODE 14 (INSIDE)FROM SHEET 12 :

$$X = 0.518$$

$$Y = 0.659$$

$$\delta = 1 - 0.518 + 0.659 - 2 [0.659 (1 - 0.518)]^{1/2}$$

$$\delta = 0.0138$$

$$\epsilon_g = \frac{21.8}{24.6 \times 10^3} (0.0138) = \underline{1.22 \times 10^{-5}} \text{ PER CYCLE}$$

NODE 22 (INSIDE)FROM SHEET 13 :

$$X = 0.523$$

$$Y = 0.892$$

$$\delta = 1 - 0.523 + 0.892 - 2 [0.892 (1 - 0.523)]^{1/2}$$

$$\delta = 0.0644$$

$$\epsilon_g = \frac{21.6}{24.6 \times 10^3} (0.0644) = \underline{5.66 \times 10^{-5}} \text{ PER CYCLE}$$

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NUMBER E-4SHEET 17 OF 20DATE 2-2-73 BY HEILKERCHARGE NO. D-51100
DESCRIPTION PRESSURE TUBE AT SODIUM -
ARGON INTERFACE

CHECK DATE _____ BY _____

FULL RELAXATION BREE METHOD CONT'DNODE 14 (INSIDE)

SINCE MOST OF THE THERMAL CYCLING OCCURS BETWEEN CONDITION A AND CONDITION B, IT WILL CONSERVATIVELY BE ASSUMED THAT THERE ARE 30,000 CYCLES OF THE PLASTIC STRAIN INCREMENT CALCULATED ON THE PRECEDING SHEET FOR NODE 14 INSIDE.

$$\epsilon_p = N \epsilon_g = 30,000 (1.22 \times 10^{-5}) = 0.366$$

$$\epsilon_p / \epsilon_{\text{ALLOW}} = \frac{0.366}{0.02} = 18.3 > 1.0$$

THEREFORE THIS METHOD OF CALCULATING THE INELASTIC PLASTIC STRAIN IS TOO CONSERVATIVE AND A MORE RIGOROUS METHOD IS REQUIRED.

NODE 22 (INSIDE)

SINCE THE STRESS RANGE BETWEEN CONDITION A AND CONDITION B IS SMALL, IT WILL BE ASSUMED THAT THE CYCLING OCCURS BETWEEN CONDITION B AND AMBIENT. THERE ARE 600 CYCLES OF THE PLASTIC STRAIN INCREMENT CALCULATED ON THE PRECEDING SHEET FOR NODE 22 INSIDE.

$$\epsilon_p = N \epsilon_g = 600 (5.66 \times 10^{-5}) = 0.034$$

$$\epsilon_p / \epsilon_{\text{ALLOW}} = \frac{0.034}{0.02} = 1.7 > 1.0$$

THEREFORE THIS METHOD OF CALCULATING THE INELASTIC PLASTIC STRAIN IS TOO CONSERVATIVE AND A MORE RIGOROUS METHOD IS REQUIRED.

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NUMBER E-4

SHEET 18 OF 20

DATE 2-2-73 BY HEILKER

CHECK DATE _____ BY _____

CHARGE NO. D-51100

DESCRIPTION PRESSURE TUBE AT SODIUM-
ARGON INTERFACE

LONG TERM CREEP (SECONDARY)

THE CREEP STRAIN WILL BE UNIFORM
THROUGHOUT THE TUBE. IT IS CAUSED BY
THE CONSTANT PRIMARY STRESS LOADING
OVER THE UNIT'S 30 YEAR LIFETIME.

FOR A PRIMARY STRESS LEVEL OF 11.29 KSI ,
AND A TEMPERATURE LEVEL OF 750°F ,
THE SECONDARY CREEP IS NEGLIGIBLE .

THUS $\epsilon_c = 0$.

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NUMBER E-4

SHEET 19 OF 20

DATE 2-2-73 BY HEILKER

CHECK DATE _____ BY _____

CHARGE NO. D-51100
DESCRIPTION PRESSURE TUBE AT SODIUM-
ARGON INTERFACE

FATIGUE

NODE 14 (INSIDE)

(CONDITION B-FLUCT.) TO (AMBIENT)

$$\text{STRESS RANGE} = 25.65 - 0 = 25.65 \text{ KSI}$$

$$\text{ALTERNATING STRESS} = \frac{25.65}{2} = 12.83 \text{ KSI}$$

FROM REF. 1 FIG. I-9-1

$$S_a = \frac{E_{30}}{E} \nabla = \frac{30}{24.6} (12.83) = 15.65 \text{ KSI}$$

$$\text{NUMBER OF CYCLES} = 300,000$$

$$n/N_d = \frac{600}{300,000} = 0.0020$$

(CONDITION B-FLUCT.) TO (CONDITION A-STEADY)

$$\text{STRESS RANGE} = 25.65 - 12.85 = 12.80 \text{ KSI}$$

$$\text{ALTERNATING STRESS} = \frac{12.80}{2} = 6.40 \text{ KSI}$$

$$S_a = \frac{E_{30}}{E} \nabla = \frac{30}{26.4} (6.40) = 7.27 \text{ KSI} < 13.0 \text{ KSI}$$

$$n/N_d = 0$$

$$\sum n/N_d = 0.0020 + 0 = \underline{0.0020}$$

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NUMBER E-4SHEET 20 OF 20DATE 2-2-73 BY HEILKER

CHECK DATE _____ BY _____

CHARGE NO. D-51100DESCRIPTION PRESSURE TUBE AT SODIUM-
ARGON INTERFACEFATIGUE CONT'DNODE 22 (INSIDE)

(CONDITION B-FLUCT.) TO (AMBIENT)

$$\text{STRESS RANGE} = 30.55 - 0 = 30.55 \text{ KSI}$$

$$\text{ALTERNATING STRESS} = \frac{30.55}{2} = 15.28 \text{ KSI}$$

FROM REF. 1 FIG. I-9-1

$$S_q = \frac{E_{30}}{E} \tau = \frac{30}{24.6} (15.28) = 18.63 \text{ KSI}$$

$$\text{NUMBER OF CYCLES} = 120,000$$

$$n/N_d = \frac{600}{120,000} = 0.0050$$

(CONDITION B-FLUCT.) TO (CONDITION A-STEADY)

$$\text{STRESS RANGE} = 30.55 - 25.65 = 4.90 \text{ KSI}$$

$$\text{ALTERNATING STRESS} = \frac{4.90}{2} = 2.45 \text{ KSI}$$

$$S_q = \frac{E_{30}}{E} \tau = \frac{30}{24.6} (2.45) = 2.99 \text{ KSI} < 13 \text{ KSI}$$

$$n/N_d = 0$$

$$\sum n/N_d = 0.0050 + 0 = \underline{0.0050}$$