RHIC PROJECT
Brookhaven National Laboratory

50 Watt Recooler ASME Boiler Code Calculations

John DeLallo

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INTRODUCTION

This technical note contains ASME Boiler and Pressure Vessel Code calculations for the RHIC 50 watt recooler. The recooler is a heat exchanger assembly which has been designed to fit with its piping into an arc quadrupole magnet cryostat. Helium gas which passes through the magnet string is cooled to a temperature close to the temperature of the boiling liquid helium bath provided on one side of the heat exchanger. Specific performance parameters for the recooler can be found in the RHIC Design Manual.

DISCUSSION

The 50 watt recooler consists of an outer stainless steel shell surrounding ten copper U-tube heat exchanger coils. Because the recooler is contained within the non boiler code arc quadrupole magnet cryostat, the vessel does not require an ASME code stamp. However, the recooler must still meet the design requirements of the code.

The code calculations are broken down as follows:

Section 1  Maximum Internal and External Pressure of Piping Elements
1.1 Outer Helium Vessel
1.2 Helium Manifold
1.3 Demister Elbow
1.4 Level Probe Tube
1.5 Supply Flex Line
1.6 Manifold Nipple
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Section 2  Maximum Pressure for Heads
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4.1 Manifold Feedthrough Recooler
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4.3 Adapter Manifold Feedthrough

Section 5  Maximum Internal Pressure of Vessels with Ligaments
5.1 Helium Manifolds
CALCULATION RESULTS

The details of the calculations are contained in Appendix A under appropriate section titles. All formulas were taken from ASME BPV Code (July 1992), Section VII, Division 1. The code calculations are solved using MathCAD software. The reader is referenced to RHIC assembly drawing 34015000 for specific design details.

CONCLUSION

The 50 Watt Re cooler meets the requirements of the ASME BPV Code. Another technical note will cover the strength of the Re cooler's interconnecting piping.
APPENDIX A - Calculations
SECTION 1 - Maximum Internal and External Pressure of Piping Elements

Given for all calculations:

- \( P = 275 \text{ psi} \) Maximum RHIC Cryogenic System Operating Pressure
- \( S = 14200 \text{ psi} \) Maximum Allowable Stress, material is TP304L or TP316L SST, A-269. The value used is lowest for both materials and for seamless or welded tube (see Section II, Part D, p86).
- \( L = 60 \text{ in} \) Pipe length for external pressure, assume all tubes 60" long
- \( E_c = 0.7 \) Full penetration w/o backing, UW-12, Type 1, No R.E. Standard weld used for welded tube.

User defined functions:

- \( R(d,t) := \frac{d}{2} - t \) Inner Radius
- \( t_c(d,t,e,s) := \frac{P \cdot R(d,t)}{s \cdot e - 0.6 \cdot P} \) Circumferential Stress, UG-27(o)(1)
- \( t_l(d,t,e,s) := \frac{P \cdot R(d,t)}{2 \cdot s \cdot e + 0.4 \cdot P} \) Longitudinal Stress, UG-27(o)(2)
- \( P_a(d,t,b) := \frac{4 \cdot b}{3 \cdot \frac{d}{t}} \) Cylindrical Shells Under External Pressure, UG-28(o)(1), Do/t >=10

Calculation 1.1 - Outer helium vessel, (see Dwg 34015001 for details)

\[ \frac{D_o}{T_o} = 66.7 \]

- \( D_o := 8 \text{ in} \) Design OD of Shell
- \( T_o := 0.120 \text{ in} \) Design Wall thickness of Shell
- \( E_1 := 0.65 \) Single butt w/ backing, UW-12, Type 2, No R.E.

- \( \frac{D_o}{T_o} = 66.7 \]

A := 0.0003 A Factor, Section II, Part D, FIG. G p674

B := 4200 psi B Factor, Section II, Part D, FIG. HA-3 p681

- \( t_c(D_o,T_o,E_1,S) = 0.109 \text{ in} \) Required Wall, circumferential stress
- \( t_l(D_o,T_o,E_1,S) = 0.057 \text{ in} \) Required Wall, longitudinal stress
- \( P_a(D_o,T_o,B) = 84 \text{ psi} \) Max External Pressure

This part meets code requirements.
Calculation 1.2 - Helium Manifold. (see Dwg 34015005, & 34015006 for details)

\[ \frac{D_o}{T_o} = 34.6 \]

\[ \frac{L}{D_o} = 26.7 \quad A := 0.001 \quad \text{A Factor, Section II, Part D, FIG. G p674} \]

\[ t_c(D_o, T_o, E_c, S) = 0.03 \text{ in} \quad \text{Required Wall, circumferential stress} \]

\[ t_1(D_o, T_o, E_1, S) = 0.017 \text{ in} \quad \text{Required Wall, longitudinal stress} \]

\[ P_a(D_o, T_o, B) = 335 \text{ psi} \quad \text{Max External Pressure} \]

*This part meets code requirements.*

Calculation 1.3 - Demister Elbow. (see Dwg 34015061 for details)

\[ \frac{D_o}{T_o} = 23.1 \]

\[ \frac{L}{D_o} = 40 \quad A := 0.0025 \quad \text{A Factor, Section II, Part D, FIG. G p674} \]

\[ t_c(D_o, T_o, E_c, S) = 0.019 \text{ in} \quad \text{Required Wall, circumferential stress} \]

\[ t_1(D_o, T_o, E_1, S) = 0.011 \text{ in} \quad \text{Required Wall, longitudinal stress} \]

\[ P_a(D_o, T_o, B) = 636 \text{ psi} \quad \text{Max External Pressure} \]

*This part meets code requirements.*

Calculation 1.4 - Level Probe Tube. (see Dwg 34015019 for details)

\[ \frac{D_o}{T_o} = 21.4 \]

\[ \frac{L}{D_o} = 80 \quad A := 0.0028 \quad \text{A Factor, Section II, Part D, FIG. G p674} \]

\[ t_c(D_o, T_o, E_c, S) = 0.01 \text{ in} \quad \text{Required Wall, circumferential stress} \]

\[ t_1(D_o, T_o, E_1, S) = 0.005 \text{ in} \quad \text{Required Wall, longitudinal stress} \]

\[ P_a(D_o, T_o, B) = 684 \text{ psi} \quad \text{Max External Pressure} \]

*This part meets code requirements.*
Calculation 1.5 - Supply Flex Line (see Dwg 34015087 for details)

\[ \frac{D_o}{T_o} = 14.3 \]

\[ \frac{L}{D_o} = 120 \]

\[ A := 0.005 \]

\[ B := 12000 \text{ psi} \]

\[ t_c(D_o, T_o, E_c, S) = 0.006 \text{ in} \]

\[ t_l(D_o, T_o, E_l, S) = 0.003 \text{ in} \]

\[ P_a(D_o, T_o, B) = 1120 \text{ psi} \]

This part meets code requirements.

Calculation 1.6 - Manifold Nipple (see Dwg 34015010 for details)

\[ \frac{D_o}{T_o} = 25.9 \]

\[ \frac{L}{D_o} = 40 \]

\[ A := 0.0017 \]

\[ B := 10000 \text{ psi} \]

\[ t_c(D_o, T_o, E_c, S) = 0.019 \text{ in} \]

\[ t_l(D_o, T_o, E_l, S) = 0.011 \text{ in} \]

\[ P_a(D_o, T_o, B) = 516 \text{ psi} \]

This part meets code requirements.

Calculation 1.7 - Manifold Adapter (see Dwg 34015025 for details)

\[ \frac{D_o}{T_o} = 14.7 \]

\[ \frac{L}{D_o} = 120 \]

\[ A := 0.005 \]

\[ B := 12000 \text{ psi} \]

\[ t_c(D_o, T_o, E_c, S) = 0.006 \text{ in} \]

\[ t_l(D_o, T_o, E_l, S) = 0.003 \text{ in} \]

\[ P_a(D_o, T_o, B) = 1088 \text{ psi} \]

This part meets code requirements.
Calculation 1.8 - Copper Fin Tube (see Dwg 34015011 & 34015012 for details)

Note: tubing is now brazed copper which has different S, and E values.

\[ S_{cop} := 9000 \text{ psi} \]

Maximum Allowable Stress for Nonferrous Materials

Material is seamless U-bend tube C12200 Cu, B-395.

(Values from Section II, Part D, pg 216)

\[ D_o := 0.5 \text{ in} \]

Design OD of Shell

\[ T_o := 0.035 \text{ in} \]

Design Wall thickness of Shell

\[ E_c := 1.0 \]

Seamless tube, UB-14 (a)

\[ E_1 := 0.50 \]

Brazed joint, no internal visual exam, UB-14 (b)

\[ \frac{D_o}{T_o} = 14.3 \]

\[ \frac{L}{D_o} = 120 \]

\[ A := 0.005 \]

A Factor, Section II, Part D, FIG. G p674

\[ B := 5600 \text{ psi} \]

B Factor, Section II, Part D, FIG. NFC-3 p693

\[ t_c(D_o, T_o, E_c, S_{cop}) = 0.007 \text{ in} \]

Required Wall, circumferential stress

\[ t_l(D_o, T_o, E_1, S_{cop}) = 0.006 \text{ in} \]

Required Wall, longitudinal stress

\[ P_a(D_o, T_o, B) = 523 \text{ psi} \]

Max External Pressure

This part meets code requirements.
SECTION 2 - Maximum Pressure for Heads

P := 275·psi  Maximum RHIC Cryogenic System Operating Pressure
S := 16300·psi Maximum Allowable Stress, material is 304L SST, A-240.
       (see Section II, Part D, p86)
E := 0.60  Single-weld butt w/o backing, UW-12, Type 3, No R.E.

Calculation 2.1 - Helium Manifold Upper (see Dwg34015005 & 34015007)

d := 2.12·in  Diameter exposed to pressure, ID of 2.25 OD x 0.065 Wall tube.

\[ t_s := 0.065 \]  Wall thickness of part 34015005
\[ t_r := 0.03 \]  Required wall thickness (see Calculation 1.2)
C := 0.33  Configuration similar to Fig UG-34 sketch (h), ts > 1.25t

\[ t := d \cdot \frac{C \cdot P}{S \cdot E} \]  Required thickness, unstayed flat heads
       and covers, UG-34 (c)(2)
\[ t = 0.204 \cdot \text{in} \]

This part meets code requirements. - Plate design thickness equals 0.25"

Calculation 2.2 - Helium Manifold Lower (see Dwg34015006 & 34015076)

C := 0.33  Physical configuration similar to that of Calculation 2.1

Since plate is bent at 40deg, assume it is 2 separate flat heads with dimensions corresponding to the bend.

\[ D_1 := 2.10 \cdot \text{in} \]  Long span
\[ D_2 := 2.10 \cdot \text{in} \]  Long span
\[ d_1 := 0.675 \cdot \text{in} \]  Short span
\[ d_2 := 2.00 \cdot \text{in} \]  Short span

Required thickness, Unstayed Flat Heads and Covers, UG-34 (c)(3)

\[ Z_1 := 3.4 - \frac{2.4 \cdot d_1}{D_1} \]
\[ Z_2 := 3.4 - \frac{2.4 \cdot d_2}{D_2} \]

\[ t_1 := d_1 \cdot \sqrt{\frac{Z_1 \cdot C \cdot P}{S \cdot E}} \]  \[ t_1 = 0.105 \cdot \text{in} \]
\[ t_2 := d_2 \cdot \sqrt{\frac{Z_2 \cdot C \cdot P}{S \cdot E}} \]  \[ t_2 = 0.203 \cdot \text{in} \]

This part meets code requirements. - Plate design thickness equals 0.25".
Calculation 2.3 - 50 watt Recooler Head. (see Dwg 34015002 & 34015078 for details)

- $D_0 := 8\text{-in}$: Design OD of head skirt
- $T := 0.140\text{-in}$: Design wall thickness of head
- $L := 8.0\text{-in}$: Inside crown radius equals skirt OD
- $R_o := 8.14\text{-in}$: Outside crown radius
- $E := 1.0$: Seamless

- $t := \frac{0.885 \cdot P \cdot L}{S \cdot E - 0.1 \cdot P}$: Required thickness, internal pressure torispherical head, UG-32 (e)

Max external pressure, UG-33 (a). Max pressure is the lesser of $P_{a1}$ or $P_{a2}$

- $\frac{S \cdot E}{0.1 + \frac{0.885 \cdot L}{T}} = 1.67$ $P_{a1} = 193\text{ psi}$
- $A := \frac{0.125}{\frac{R_o}{T}}$ $A = 0.002$

- $B := 10000\text{-psi}$: B Factor, Section II, PartD, Fig. HA-3, p681

- $P_{a2} := \frac{B}{\frac{R_o}{T}}$ $P_{a2} = 172\text{ psi}$

This part meets code requirements.
SECTION 3 - Strength of Nozzles with Dual Fillet Welds

P := 275-psi  Maximum RHIC Cryogenic System Operating Pressure
Section II, Part D, p86
S_n := S  S_v := S  Allowable Stress for nozzle and vessel, both are the same.
f_{r1} := 1  f_{r2} := 1  Strength reduction factors equal unity because materials are identical
E := 1.0  Joint efficiency for required wall thickness (UG-37 (a), p47)
F := 1.0  Correction factor, 1 for all applications (UG-37 (a), p47)
E_1 := 1.0  Opening in solid plate (UG-37 (a), p47)
leg := 0.06-in  0.06" fillet on inside and outside of vessel, Fig UW-16.1 (i)
c := 0-in  No corrosion allowance

Common calculations:
- Actual t_1 and t_2 dimensions
  \[ t_1 := 0.7 \cdot \text{leg} \quad t_2 := t_1 \quad t_1 = 0.042 \text{-in} \]
- \( A_{41} \) and \( A_{42} \) = Area available in weld
  \[ A_{41} := \text{leg} \cdot f_{r2} \quad A_{42} := A_{41} \quad A_{41} = 0.004 \text{-in}^2 \]
- \( A_5 \) and \( A_{42} = 0 \) (from geometry of weld)
  \[ A_5 := 0 \text{-in}^2 \quad A_{42} := 0 \text{-in}^2 \]
- Fillet weld Shear
  \[ \tau_w := 0.49 \cdot S_n \quad \tau_w = 6958 \text{ psi} \]
- Nozzle wall shear
  \[ \tau_n := 0.7 \cdot S_n \quad \tau_n = 9940 \text{ psi} \]

User defined functions
- Circumferential Stress, UG-27(c)(1)−
  \[ t_{\text{calc}}(D, T) := \frac{P \cdot \left( \frac{D}{2} - T \right)}{S \cdot E - 0.6 \cdot P} \]
- Area of Reinforcement Fig. UG-37.1−
  \[ A(D, Tr, Tn) := D \cdot Tr \cdot F + 2 \cdot Tn \cdot Tr \cdot F \cdot (1 - f_{r1}) \]
  \[ A_{1a}(T, Tr, Tn) := 2 \cdot (T + Tn) \cdot (E_1 \cdot T - F \cdot Tr) - 2 \cdot Tn \cdot (E_1 \cdot T - F \cdot Tr) \cdot (1 - f_{r1}) \]
  \[ A_{1b}(D, T, Tr, Tn) := D \cdot (E_1 \cdot T - F \cdot Tr) - 2 \cdot Tn \cdot (E_1 \cdot T - F \cdot Tr) \cdot (1 - f_{r1}) \]
  \[ A_{2a}(T, Tn, Trm) := 5 \cdot (Tn - Trm) \cdot f_{r2} \cdot T \]
  \[ A_{2b}(Tn, Trm) := 5 \cdot (Tn - Trm) \cdot f_{r2} \cdot Tn \]
  \[ A_{3}(h, Tn) := 2 \cdot (Tn - c) \cdot f_{r2} \cdot h \]

Strength of Connection Elements:
- \[ F_{\text{weld}}(Dn) := \frac{\pi}{2} \cdot Dn \cdot \text{leg} \cdot \tau_w \]
- \[ F_{\text{wall}}(D, Dn, Tn) := \frac{\pi}{2} \cdot \left( \frac{Dn + D}{2} \right) \cdot Tn \cdot \tau_n \]
Calculation 3.1 - Helium Supply Feedthrough. (see Dwg 34015000 & 34015026 for details)

Shell Dimensions

- D := 8-in
- t := 0.12-in

Nozzle Dimensions

- D_n := 0.5-in
- t_n := 0.035-in

Outer diameter

- d := D_n - 2.t_n
- d = 0.43-in

Wall thickness

- t_r := t_{calc}(D, t)
- t_r = 0.076-in

- t_m := t_{calc}(D_n, t_n)
- t_m = 0.004-in

Finished diameter of circular opening

Required wall thickness shell

Required wall thickness nozzle

Minimum requirements for attachment welds at openings, UW-16, (d)(1)

- t_min = lesser of .75" or t of thinner part
- t_min := t_n
- t_{min} = 0.035-in

- t_1 and t_2 > smaller of .25" or .7*t_{min}
- t_1 = 0.042-in
- 0.7*t_{min} = 0.025-in

- t_1 + t_2 > 1.25 * T_{min}
- t_1 + t_2 = 0.084-in
- 1.25*t_{min} = 0.044-in

Cover weld is satisfactory

Area of reinforcement required

- A_{req} := A(d, t_r, t_n)
- A_{req} = 0.033-in^2

Area of reinforcement available

- A_1 := Larger of the following:
  - A_{1a}(t, t_r, t_n) = 0.014-in^2
  - A_{1b}(d, t, t_r, t_n) = 0.019-in^2

- A_2 := Smaller of the following:
  - A_{2a}(t, t_n, t_m) = 0.018-in^2
  - A_{2b}(t_n, t_m) = 0.005-in^2

- A_3 := The following:
  - A_{3}(h, t_n) = 0.006-in^2

Total area available

- A_{total} := A_1 + A_2 + A_3 + A_{41} + A_{43}
- A_{total} = 0.038-in^2

Since A_{total} > A_{req}, additional reinforcing elements are not needed.

Calculate strength of reinforcement UG-41.1 (a)

Total Weld Load

- W := [A_{req} - (d - 2.t_n)](E_1.t - F.t_r) \cdot S_v
- W = 239-lbf

Path 1-1

- W_{11} := (A_2 + A_5 + A_{41} + A_{42}) \cdot S_v
- W_{11} = 128-lbf

Path 2-2

- W_{22} := (A_2 + A_3 + A_{41} + A_{43} + 2.t_n.t.f_r1) \cdot S_v
- W_{22} = 385-lbf

Check strength paths

- F_{weld}(D_n) = 328-lbf
- F_{wall}(d, D_n, t_n) = 254-lbf

Path 1-1

- F_{11} := F_{weld}(D_n) + F_{wall}(d, D_n, t_n)
- F_{11} = 582-lbf

Path 2-2

- F_{22} := 2.F_{weld}(D_n)
- F_{22} = 656-lbf

Part meets code requirements. - All paths are stronger than the required strength.
Calculation 3.2 - Level Probe Feedthrough, (see Dwg 34015000 & 34015019 for details)

Given:

- Shell Dimensions: \( D : = 8 \text{-in} \)
  \( t : = 0.12 \text{-in} \)
- Nozzle Dimensions: \( D_n : = 0.75 \text{-in} \)
  \( t_n : = 0.035 \text{-in} \)

Finished diameter of circular opening: \( d : = D_n - 2 \cdot t_n \)
\( d \) = 0.68 in

Required wall thickness shell: \( t_r : = t_{\text{calc}}(D, t) \)
\( t_r \) = 0.076 in

Required wall thickness nozzle: \( t_{mn} : = t_{\text{calc}}(D_n, t_n) \)
\( t_{mn} \) = 0.007 in

Minimum requirements for attachment welds at openings, UW-16, (d)(1)

- \( t_{\text{min}} \) = lesser of .75\(^{\circ}\) or \( t \) of thinner part
  \( t_{\text{min}} : = t_n \)

- \( t_1 \leq 0.042 \text{ in} \)
- \( 0.7 \cdot t_{\text{min}} \leq 0.025 \text{ in} \)
- \( 1.25 \cdot t_{\text{min}} \leq 0.044 \text{ in} \)

Cover weld is satisfactory

Area of reinforcement required
\( A_{\text{req}} : = A(d, t_r, t_n) \)
\( A_{\text{req}} \) = 0.052 \text{ in}^2

Area of reinforcement available

\( A_1 \) = Larger of the following:
\( A_{1a} : = A_{1b}(d, t, t_r, t_n) \)
\( A_{1a} \) = 0.014 \text{ in}^2
\( A_{1b} : = 0.03 \text{ in}^2 \)

\( A_2 \) = Smaller of the following:
\( A_{2a} : = A_{2b}(t, t_n, t_{mn}) \)
\( A_{2a} \) = 0.017 \text{ in}^2
\( A_{2b} : = 0.005 \text{ in}^2 \)

\( h \) = smaller of the following:
\( 2.5 \cdot t = 0.3 \text{ in} \)
\( 2.5 \cdot t_n = 0.088 \text{ in} \)

\( A_3 \) = The following:
\( A_3(h, t_n) = 0.006 \text{ in}^2 \)

Total area available
\( A_{\text{total}} : = A_1 + A_2 + A_3 + A_41 + A_43 \)
\( A_{\text{total}} = 0.048 \text{ in}^2 \)

Since \( A_{\text{total}} \gg A_{\text{req}} \) additional reinforcing elements are not needed.

Calculate strength of reinforcement UG-41.1 (a)

Total Weld Load
\( W : = [A_{\text{req}} - (d - 2 \cdot t_n) \cdot (E_1 \cdot t - F \cdot t_n)] \cdot S_v \)
\( W = 353 \text{ lbf} \)

Path 1-1
\( W_{11} : = (A_2 + A_5 + A_41 + A_42) \cdot S_v \)
\( W_{11} = 122 \text{ lbf} \)

Path 2-2
\( W_{22} : = (A_2 + A_3 + A_41 + A_43 + 2 \cdot t_n \cdot f_{r1}) \cdot S_v \)
\( W_{22} = 379 \text{ lbf} \)

Check strength paths

\( F_{\text{weld}}(D_n) = 492 \text{ lbf} \)
\( F_{\text{wall}}(d, D_n, t_n) = 391 \text{ lbf} \)

Path 1-1
\( F_{11} : = F_{\text{weld}}(D_n) + F_{\text{wall}}(d, D_n, t_n) \)
\( F_{11} = 883 \text{ lbf} \)

Path 2-2
\( F_{22} : = 2 \cdot F_{\text{weld}}(D_n) \)
\( F_{22} = 984 \text{ lbf} \)

*Part meets code requirements.* - All paths are stronger than the required strength.
Calculation 3.3 - Demister Assembly Feedthrough. (see Dwg 34015000, 34015001, & 34015065 for details)

Shell Dimensions
D := 8-in
D_n := 1.5-in

Nozzle Dimensions
t := 0.12-in
t_n := 0.049-in

Outer diameter
Wall thickness

Finished diameter of circular opening
d := D_n - 2·t_n
d = 1.402·in

Required wall thickness shell
t_r := t_{calc}(D, t)
t_r = 0.076·in

Required wall thickness nozzle
t_m := t_{calc}(D_n, t_n)
t_m = 0.014·in

Minimum requirements for attachment welds at openings, UW-16, (d)(1)

\[ t_{\text{min}} = \text{lesser of } 0.75\text{ in or } t \text{ of thinner part} \]
\[ t_{\text{min}} := t_n \]

\[ t_1 + t_2 > 1.25 \cdot T_{\text{min}} \]
\[ t_1 + t_2 = 0.084\text{ in} > 1.25 \cdot t_{\text{min}} = 0.061\text{ in} \]

Cover weld is satisfactory

Area of reinforcement required
\[ A_{\text{req}} := A(d, t_r, t_n) \]
\[ A_{\text{req}} = 0.107\text{ in}^2 \]

Area of reinforcement available

\[ A_1 := A_{1a}(t, t_r, t_n) = 0.015\text{ in}^2 \]
\[ A_{1b}(d, t, t_r, t_n) = 0.062\text{ in}^2 \]

\[ A_2 := A_{2a}(t, t_n, t_m) = 0.021\text{ in}^2 \]
\[ A_{2b}(t_n, t_m) = 0.009\text{ in}^2 \]

\[ h := 2.5\cdot t_n \]
\[ 2.5\cdot t = 0.3\text{ in} \]

\[ A_3 := A_3(h, t_n) = 0.012\text{ in}^2 \]

Total area available
\[ A_{\text{total}} := A_1 + A_2 + A_3 + A_{41} + A_{43} \]
\[ A_{\text{total}} = 0.089\text{ in}^2 \]

Since \( A_{\text{total}} \gg A_{\text{req}} \), additional reinforcing elements are not needed.

Calculate strength of reinforcement UG-41.1 (a)

Total Weld Load
\[ W := [A_{\text{req}} - (d - 2\cdot t_n) \cdot E_1 \cdot t - F \cdot t_r] \cdot S_v \]
\[ W = 699\text{ lbf} \]

Path 1-1
\[ W_{11} := (A_2 + A_5 + A_{41} + A_{42}) \cdot S_v \]
\[ W_{11} = 174\text{ lbf} \]

Path 2-2
\[ W_{22} := (A_2 + A_3 + A_{41} + A_{43} + 2\cdot t_n \cdot f_{r1}) \cdot S_v \]
\[ W_{22} = 562\text{ lbf} \]

Check strength paths

\[ F_{\text{weld}}(D_n) = 984\text{ lbf} \]
\[ F_{\text{wall}}(d, D_n, t_n) = 1110\text{ lbf} \]

Path 1-1
\[ F_{11} := F_{\text{weld}}(D_n) + F_{\text{wall}}(d, D_n, t_n) \]
\[ F_{11} = 2094\text{ lbf} \]

Path 2-2
\[ F_{22} := 2\cdot F_{\text{weld}}(D_n) \]
\[ F_{22} = 1967\text{ lbf} \]

Part meets code requirements. - All paths are stronger than the required strength
SECTION 4.0 - Strength of Nozzles with Grove and Covering Fillet Welds

P := 275-psi  Maximum RHIC Cryogenic System Operating Pressure
Because A-269 is not listed in BPV, SA-213 is used to find S.
(Value from Section II, Part D, p.86)
S_n := S  S_y := S  Allowable Stress for nozzle and vessel, both are the same.
f_{r_1} := 1  f_{r_2} := 1  Strength reduction factors equal unity because materials are identical.
E := 1.0  Joint efficiency for required wall thickness (from UG-37 (a), p.47)
F := 1  Correction factor, 1 for all applications (p.47)
E_1 := 1  Opening in solid plate
h := 0.3-in  No corrosion allowance

User defined functions:

Circumferential Stress, UG-27(c)(1):
\[ t_{\text{calo}}(D, T) := \frac{P \left( \frac{D}{2} - T \right)}{S \cdot E - 0.6 \cdot P} \]

Area of Reinforcement Fig. UG-37.1:
\[ A(D, Tr, Tn) := D \cdot Tr \cdot F + 2 \cdot Tn \cdot Tr \cdot F \cdot (1 - f_{r_1}) \]
\[ A_{1a}(T, Tr, Tn) := 2 \cdot (T + Tn) \cdot (E_1 \cdot T - F \cdot Tr) - 2 \cdot Tn \cdot (E_1 \cdot T - F \cdot Tr) \cdot (1 - f_{r_1}) \]
\[ A_{1b}(D, T, Tr, Tn) := D \cdot (E_1 \cdot T - F \cdot Tr) - 2 \cdot Tn \cdot (E_1 \cdot T - F \cdot Tr) \cdot (1 - f_{r_1}) \]
\[ A_{2a}(T, Tn, Trm) := 5 \cdot (Tn - Trm) \cdot f_{r_2} \cdot T \]
\[ A_{2b}(Tn, Trm) := 5 \cdot (Tn - Trm) \cdot f_{r_2} \cdot Tn \]
\[ A_3(h, Tn) := 2 \cdot (Tn - c) \cdot f_{r_2} \cdot h \]
Calculation 4.1 - Manifold Feedthrough Recoler. (see Dwg 34015000, 34015010, & 34015002 for details)

Shell Dimensions  Nozzle Dimensions
D := 8.0-in  D_n := 1.625-in  Outer diameter
\( t := 0.12\)-in  \( t_n := 0.120\)-in  Wall thickness
\( \text{leg} := 0.13\)-in  Fillt cover-weld size

Finished diameter of circular opening
\( d := D_n - 2 \cdot t_n \)  \( d = 1.385\)-in

Required wall thickness shell
\( t_r := t_{\text{calc}}(D,t) \)  \( t_r = 0.076\)-in

Required wall thickness nozzle
\( t_{rn} := t_{\text{calc}}(D_n \cdot t_n) \)  \( t_{rn} = 0.014\)-in

Minimum requirements for attachment welds at openings, UW-16, (d)(1)
\( t_{\text{min}} = \text{lesser of}.75^\circ \text{ or } t \text{ of thinner part} \)
\( t_{\text{min}} := t_n \)  \( t_{\text{min}} = 0.12\)-in

\( t_c > \text{smaller of}.25^\circ \text{ or }.7 \cdot t_{\text{min}} \)
\( t_c := 0.7 \cdot \text{leg} \)  \( t_c = 0.091\)-in  \( > 0.7 \cdot t_{\text{min}} = 0.084\)-in

Cover weld is satisfactory

Area of reinforcement required
\( A_{\text{req}} := A/d, t_r, t_n \)  \( A_{\text{req}} = 0.105\)-in²

Area of reinforcement available
\( A_1 = \text{Larger of the following:} \)
\( A_{1a} := A_{1b}(d, t, t_r, t_n) = 0.021\)-in²
\( A_{1a}(d, t, t_r, t_n) = 0.061\)-in²

\( A_2 = \text{Smaller of the following:} \)
\( A_{2a}(t, t_n, t_{rn}) = 0.064\)-in²
\( A_{2b}(t_n, t_{rn}) = 0.064\)-in²

\( h = \text{smaller of the following:} \)
\( 2.5 \cdot t = 0.3\)-in
\( 2.5 \cdot t_n = 0.3\)-in

\( h := 2.5 \cdot t_n \)

\( A_3 = \text{The following:} \)
\( A_3 := A_3(h, t_n) \)  \( A_3 = 0.072\)-in²

\( A_41 = \text{The following} \)
\( A_{41} := \text{leg}^2 \delta r_2 \)  \( A_{41} = 0.017\)-in²

Total area available
\( A_{\text{total}} := A_1 + A_2 + A_3 + A_{41} \)  \( A_{\text{total}} = 0.214\)-in²

Since \( A_{\text{total}} > A_{\text{req}} \) additional reinforcing elements are not needed.

Strength calculations for attachment welds are not required for this detail which conforms with Fig. UW-16.1 sketch (c) [see UW-15 (b)]

This part meets code requirements.
Calculation 4.2 - Manifold Nipple Feedthrough, (see Dwg 34015003, 34015004, & 34015010 for details)

Shell Dimensions  Nozzle Dimensions
D := 2.25-in  D_n := 1.515-in  Outer diameter
\( t := 0.065\text{-in} \)  \( t_n := 0.065\text{-in} \)  Wall thickness
\( \text{leg} := 0.07\text{-in} \)  \( \text{fillet} \)

Finished diameter of circular opening
\( d := D_n - 2 \cdot t_n \)
\( d = 1.385\text{-in} \)

Required wall thickness shell
\( t_r := t_{calc}(D, t) \)
\( t_r = 0.021\text{-in} \)

Required wall thickness nozzle
\( t_{rn} := t_{calc}(D_n, t_n) \)
\( t_{rn} = 0.014\text{-in} \)

Minimum requirements for attachment welds at openings, UW-16, (d)(1)
\( t_{\text{min}} = \text{lesser of .75" or } t \text{ of thinner part} \)
\( t_{\text{min}} := t_n \quad t_{\text{min}} = 0.065\text{-in} \)

\( t_c > \text{smaller of .25" or } 0.7 \cdot t_{\text{min}} \)
\( t_c := 0.7 \cdot \text{leg} \quad t_c = 0.049\text{-in} > 0.7 \cdot t_{\text{min}} = 0.045\text{-in} \)

Cover weld is satisfactory

Area of reinforcement required
\( A_{\text{req}} := A(d, t_r, t_n) \)
\( A_{\text{req}} = 0.029\text{-in}^2 \)

Area of reinforcement available
\( A1 = \text{Larger of the following:} \)
\( A1 := A_{1a}(t, t_r, t_n) = 0.011\text{-in}^2 \)
\( A_{1b}(d, t, t_r, t_n) = 0.061\text{-in}^2 \)

\( A2 = \text{Smaller of the following:} \)
\( A_{2a}(t, t_n, t_{rn}) = 0.017\text{-in}^2 \)
\( A_{2b}(t_n, t_{rn}) = 0.017\text{-in}^2 \)

\( h = \text{smaller of the following:} \)
\( 2.5 \cdot t = 0.163\text{-in} \)
\( 2.5 \cdot t_n = 0.163\text{-in} \)

\( A3 = \text{The following:} \)
\( A3 := A_3(h, t_n) \)
\( A3 = 0.021\text{-in}^2 \)

\( A41 = \text{The following:} \)
\( A41 := \text{leg}^2 \cdot t_r^2 \)
\( A41 = 0.005\text{-in}^2 \)

Total area available
\( A_{\text{total}} := A1 + A2 + A3 + A41 \)
\( A_{\text{total}} = 0.104\text{-in}^2 \)

Since \( A_{\text{total}} > A_{\text{req}} \) additional reinforcing elements are not needed.

Strength calculations for attachment welds are not required for this detail which conforms with Fig. UW-16.1 sketch (c) [see UW-15 (b)]

This part meets code requirements.
**Calculation 4.3 - Adapter Manifold Feedthrough. (see Dwg 34015004, 34015005, & 34015025 for details)**

**Shell Dimensions**

\[ D = 2.25 \text{-in} \quad D_n = 0.563 \text{-in} \quad \text{Outer diameter} \]

\[ t = 0.065 \text{-in} \quad t_n = 0.065 \text{-in} \quad \text{Wall thickness} \]

\[ \text{leg} = 0.07 \text{-in} \quad \text{Fillet cover-weld size} \]

**Nozzle Dimensions**

\[ d := D_n - 2 \cdot t_n \quad d = 0.433 \text{-in} \]

**Finished diameter of circular opening**

**Required wall thickness shell**

\[ t_r := t_{\text{calc}}(D, t) \quad t_r = 0.021 \text{-in} \]

**Required wall thickness nozzle**

\[ t_{rn} := t_{\text{calc}}(D_n, t_n) \quad t_{rn} = 0.004 \text{-in} \]

**Minimum requirements for attachment welds at openings, UW-16, (d)(1)**

\[ t_{\text{min}} = \text{lesser of .75" or t of thinner part} \quad t_{\text{min}} := t_n \quad t_{\text{min}} = 0.065 \text{-in} \]

\[ t_c > \text{smaller of .25" or } .7 \cdot t_{\text{min}} \quad t_c := 0.7 \cdot \text{leg} \quad t_c = 0.049 \text{-in} > 0.7 \cdot t_{\text{min}} = 0.045 \text{-in} \]

Cover weld is satisfactory

**Area of reinforcement required**

\[ A_{\text{req}} := A(d, t_r, t_n) \quad A_{\text{req}} = 0.009 \text{-in}^2 \]

**Area of reinforcement available**

\[ A1 = \text{Larger of the following:} \quad A_{1a}(d, t_r, t_n) = 0.011 \text{-in}^2 \quad A_{1b}(d, t_r, t_n) = 0.019 \text{-in}^2 \]

\[ A2 = \text{Smaller of the following:} \quad A_{2a}(t_n, t_r, t_n) = 0.02 \text{-in}^2 \quad A_{2b}(t_n, t_r, t_n) = 0.02 \text{-in}^2 \]

\[ h = \text{smaller of the following:} \quad 2.5 \cdot t = 0.163 \text{-in} \quad 2.5 \cdot t_n = 0.163 \text{-in} \]

\[ A3 = \text{The following:} \quad A3 := A_3(h, t_n) \quad A3 = 0.021 \text{-in}^2 \]

\[ A41 = \text{The following:} \quad A41 := \text{leg}^2 \cdot f_{t2} \quad A41 = 0.005 \text{-in}^2 \]

**Total area available**

\[ A_{\text{total}} := A1 + A2 + A3 + A41 \quad A_{\text{total}} = 0.065 \text{-in}^2 \]

Since \( A_{\text{total}} > A_{\text{req}} \) additional reinforcing elements are not needed.

Strength calculations for attachment welds are not required for this detail which conforms with Fig. UW-16.1 sketch (c) [see UW-15 (b)]

*This part meets code requirements.*
SECTION 5 - Maximum Internal Pressure of Vessels with Ligaments

P := 275-psi  Maximum RHIC Cryogenic System Operating Pressure

S := 14200-psi  Maximum Allowable Stress for Ferrous Materials
All material is TP304L SST, A-269.
Because A-269 is not listed in BPV, SA-213 is used to find S.
(Value from Section II, Part D, p86)

User defined functions:
  Inner Radius -
  \[ R(d,t) := \frac{d}{2} - t \]

  Circumferential Stress, UG-27(c)(1)-
  \[ t_c(d,t,e,s) := \frac{P \cdot R(d,t)}{s \cdot e - 0.6 \cdot P} \]

  Longitudinal Stress, UG-27(c)(2)-
  \[ t_l(d,t,e,s) := \frac{P \cdot R(d,t)}{2 \cdot s \cdot e + 0.4 \cdot P} \]

Calculation 5.1 Helium Manifolds (see Dwg.34015003 & 34015004)

\( d := 0.515 \text{-in} \)  Diameter of tube holes. Same for all configurations

Longitudinal ligaments. Since this is the smallest possible ligament pitch, circumferential and diagonal cases shall not be considered

\( p := 1.07 \text{-in} \)  Hole Pitch
\( \text{Le} := \frac{P - d}{p} \)
\( \text{Le} = 51.9\% \)

From UG-27 Thickness of Shells Under Internal Pressure

(b) \( E := \text{Le} \)  Joint efficiency equals ligament efficiency
\( D_o := 2.25 \text{-in} \)  Design OD of Shell
\( T_o := 0.065 \text{-in} \)  Design Wall thickness of Shell
\( R := \frac{D_o}{2} - T_o \)
\( R = 1.06 \text{-in} \)  Inside radius of shell

(c)(1) Circumferential Stress (Longitudinal Joints)
\[ t := \frac{P \cdot R}{S \cdot E - 0.6 \cdot P} \]
\( t = 0.04 \text{-in} \)

(c)(2) Longitudinal Stress (Circumferential Joints)
\[ t := \frac{P \cdot R}{2 \cdot S \cdot E + 0.4 \cdot P} \]
\( t = 0.02 \text{-in} \)

This part meets code requirements. - Required wall thickness is 0.034" design is 0.065".