AD/RHIC/RD-88

RHIC PROJECT

Brookhaven National Laboratory

50 Watt Recooler ASME Boiler Code Calculations

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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
- 1.7 Manifold Adapter
- 1.8 Copper Fin Tube

Section 2 Maximum Pressure for Heads
- 2.1 Helium Manifold Upper
- 2.2 Helium Manifold Lower
- 2.3 50 Watt Recooler Head

Section 3 Strength of Nozzles with Dual Fillet Welds
- 3.1 Helium Supply Feedthrough
- 3.2 Level Probe Feedthrough
- 3.3 Demister Assembly Feedthrough

Section 4 Strength of Nozzles with Grove and Covering Fillet Welds
- 4.1 Manifold Feedthrough Recooler
- 4.2 Manifold Nipple Feedthrough
- 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 Recooler meets the requirements of the ASME BPV Code. Another technical note will cover the strength of the Recooler's interconnecting piping.

APPENDIX A - Calculations

SECTION 1 - Maxiumum Internal and External Pressure of Piping Elements

Given for all calculations:

$P := 275 \cdot psi$	Maximum RHIC Cryogenic System Operating Pressure
$S := 14200 \cdot psi$	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).
$L := 60 \cdot in$	Pipe length for external pressure, assume all tubes 60" long
$E_c := .7$	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
$t_c(d,t,e,s) := \frac{P \cdot R(d,t)}{s \cdot e - 0.6 \cdot P}$	Cicumferential Stress, UG-27(c)(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(c)(2)
$Pa(d,t,b) := \frac{4 \cdot b}{3 \cdot \left(\frac{d}{t}\right)}$	Cylinderical Shells Under External Pressure, UG-28 (c)(1), Do/t >=10

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

$D_o := 8 \cdot in$	Design OD of Shell
$T_o := 0.120 \cdot in$	Design Wall thickness of Shell
$E_l := .65$	Single butt w/ backing, UW-12, Type 2, No R.E.

$\frac{D_o}{T_o} = 66.7$ $\quad \frac{L}{D_o} = 7.5$

$A := 0.0003$	A Factor, Section II, Part D, FIG. G p674
$B := 4200 \cdot psi$	B Factor, Section II, Part D, FIG. HA-3 p681
$t_c(D_o, T_o, E_c, S) = 0.109 \cdot in$	Required Wall, circumferential stress
$t_l(D_o, T_o, E_l, S) = 0.057 \cdot in$	Required Wall, longitudinal stress
$Pa(D_o, T_o, B) = 84 \cdot psi$	Max External Pressure

This part meets code requirements.

Calculation 1.2 - Helium Manifold. (see Dwg 34015005, & 34015006 for details)

	$D_o := 2.25 \cdot in$		Design OD of Shell
	$T_o := 0.065 \cdot in$		Design Wall thickness of Shell
	$E_1 := .60$		Single butt w/o backing, UW-12, Type 3, No R.E.
$\frac{D_o}{T_o} = 34.6$	$\frac{L}{D_o} = 26.7$	$A := 0.001$	A Factor, Section II, Part D, FIG. G p674
		$B := 8700 \cdot psi$	B Factor, Section II, Part D, FIG. HA-3 p681
	$t_c(D_o, T_o, E_c, S) = 0.03 \cdot in$		Required Wall, circumferential stress
	$t_l(D_o, T_o, E_1, S) = 0.017 \cdot in$		Required Wall, longitudinal stress
	$Pa(D_o, T_o, B) = 335 \cdot psi$		Max External Pressure

This part meets code requirements.

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

	$D_o := 1.5 \cdot in$		Design OD of Shell
	$T_o := 0.065 \cdot in$		Design Wall thickness of Shell
	$E_1 := .6$		Single butt w/o backing, UW-12, Type 3, No R.E.
$\frac{D_o}{T_o} = 23.1$	$\frac{L}{D_o} = 40$	$A := 0.0025$	A Factor, Section II, Part D, FIG. G p674
		$B := 11000 \cdot psi$	B Factor, Section II, Part D, FIG. HA-3 p681
	$t_c(D_o, T_o, E_c, S) = 0.019 \cdot in$		Required Wall, circumferential stress
	$t_l(D_o, T_o, E_1, S) = 0.011 \cdot in$		Required Wall, longitudinal stress
	$Pa(D_o, T_o, B) = 636 \cdot psi$		Max External Pressure

This part meets code requirements.

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

	$D_o := 0.75 \cdot in$		Design OD of Shell
	$T_o := 0.035 \cdot in$		Design Wall thickness of Shell
	$E_1 := .6$		Single butt w/o backing, UW-12, Type 3, No R.E.
$\frac{D_o}{T_o} = 21.4$	$\frac{L}{D_o} = 80$	$A := 0.0028$	A Factor, Section II, Part D, FIG. G p674
		$B := 11000 \cdot psi$	B Factor, Section II, Part D, FIG. HA-3 p681
	$t_c(D_o, T_o, E_c, S) = 0.01 \cdot in$		Required Wall, circumferential stress
	$t_l(D_o, T_o, E_1, S) = 0.005 \cdot in$		Required Wall, longitudinal stress
	$Pa(D_o, T_o, B) = 684 \cdot psi$		Max External Pressure

This part meets code requirements.

Calculation 1.5 - Supply Flex Line (see Dwg 34015087 for details)

	$D_o := 0.5 \cdot in$	Design OD of Shell
	$T_o := 0.035 \cdot in$	Design Wall thickness of Shell
	$E_1 := .6$	Single butt w/o backing, UW-12, Type 3, No R.E.
$\frac{D_o}{T_o} = 14.3$	$\frac{L}{D_o} = 120$ $A := 0.005$	A Factor, Section II, Part D, FIG. G p674
	$B := 12000 \cdot psi$	B Factor, Section II, Part D, FIG. HA-3 p681
	$t_c(D_o, T_o, E_c, S) = 0.006 \cdot in$	Required Wall, circumferential stress
	$t_1(D_o, T_o, E_1, S) = 0.003 \cdot in$	Required Wall, longitudinal stress
	$Pa(D_o, T_o, B) = 1120 \cdot psi$	Max External Pressure

This part meets code requirements.

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

	$D_o := 1.5 \cdot in$	Design OD of Shell (minimum)
	$T_o := 0.058 \cdot in$	Design Wall thickness of Shell (minimum)
	$E_1 := .6$	Single butt w/o backing, UW-12, Type 3, No R.E.
$\frac{D_o}{T_o} = 25.9$	$\frac{L}{D_o} = 40$ $A := 0.0017$	A Factor, Section II, Part D, FIG. G p674
	$B := 10000 \cdot psi$	B Factor, Section II, Part D, FIG. HA-3 p681
	$t_c(D_o, T_o, E_c, S) = 0.019 \cdot in$	Required Wall, circumferential stress
	$t_1(D_o, T_o, E_1, S) = 0.011 \cdot in$	Required Wall, longitudinal stress
	$Pa(D_o, T_o, B) = 516 \cdot psi$	Max External Pressure

This part meets code requirements.

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

	$D_o := 0.5 \cdot in$	Design OD of Shell (minimum)
	$T_o := 0.034 \cdot in$	Design Wall thickness of Shell (minimum)
	$E_1 := .6$	Single butt w/o backing, UW-12, Type 3, No R.E.
$\frac{D_o}{T_o} = 14.7$	$\frac{L}{D_o} = 120$ $A := 0.005$	A Factor, Section II, Part D, FIG. G p674
	$B := 12000 \cdot psi$	B Factor, Section II, Part D, FIG. HA-3 p681
	$t_c(D_o, T_o, E_c, S) = 0.006 \cdot in$	Required Wall, circumferential stress
	$t_1(D_o, T_o, E_1, S) = 0.003 \cdot in$	Required Wall, longitudinal stress
	$Pa(D_o, T_o, B) = 1088 \cdot psi$	Max External Pressure

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.

$S_{cop} := 9000 \cdot psi$ — Maximum Allowable Stress for Nonferrous Materials
Material is seamless U-bend tube C12200 Cu, B-395.
(Value from Section II, Part D, p216)

$D_o := 0.5 \cdot in$ — Design OD of Shell

$T_o := 0.035 \cdot in$ — Design Wall thickness of Shell

$E_c := 1.0$ — Seamless tube, UB-14 (a)

$E_l := 0.50$ — 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

$B := 5600 \cdot psi$ — B Factor, Section II, Part D, FIG. NFC-3 p693

$t_c(D_o, T_o, E_c, S_{cop}) = 0.007 \cdot in$ — Required Wall, circumferential stress

$t_l(D_o, T_o, E_l, S_{cop}) = 0.006 \cdot in$ — Required Wall, longitudinal stress

$Pa(D_o, T_o, B) = 523 \cdot psi$ — Max External Pressure

This part meets code requirements.

SECTION 2 - Maximum Pressure for Heads

$P := 275 \cdot psi$	Maximum RHIC Cryogenic System Operating Pressure
$S := 16300 \cdot psi$	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)

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

$t_s := .065$ Wall thickness of part 34015005

$t_r := .03$ $t_r \cdot 1.25 = 0.037$ Required wall thickness (see Calculation 1.2)

$C := 0.33$ Configuration similar to Fig UG-34 sketch (h), ts > 1.25tr

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

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.

$D_1 := 2.10 \cdot in$ Long span $D_2 := 2.10 \cdot in$ Long span

$d_1 := .675 \cdot in$ Short span $d_2 := 2.00 \cdot in$ Short span

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

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

$$t_1 := d_1 \cdot \sqrt{\frac{Z_1 \cdot C \cdot P}{S \cdot E}} \quad t_1 = 0.105 \cdot in \qquad t_2 := d_2 \cdot \sqrt{\frac{Z_2 \cdot C \cdot P}{S \cdot E}} \quad t_2 = 0.203 \cdot in$$

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

Calculation 2.3 - 50 watt Recooler Head. (see Dwg 34015002 &34015078 for details)

$D_o := 8 \cdot in$	Design OD of head skirt
$T := 0.140 \cdot in$	Design wall thickness of head
$L := 8.0 \cdot in$	Inside crown radius equals skirt OD
$R_o := 8.14 \cdot in$	Outside crown radius
$E := 1.0$	Seamless
$t := \frac{0.885 \cdot P \cdot L}{S \cdot E - 0.1 \cdot P}$ $t = 0.12 \cdot in$	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}

$$P_{a1} := \frac{\frac{S \cdot E}{0.1 + \frac{0.885 \cdot L}{T}}}{1.67} \qquad P_{a1} = 193 \cdot psi$$

$$A := \frac{0.125}{\left(\frac{R_o}{T}\right)} \qquad A = 0.002$$

$B := 10000 \cdot psi$ — B Factor, Section II, PartD, Fig. HA-3, p681

$$P_{a2} := \frac{B}{\left(\frac{R_o}{T}\right)} \qquad P_{a2} = 172 \cdot psi$$

This part meets code requirements.

SECTION 3 - Strength of Nozzles with Dual Fillet Welds

$P := 275 \cdot psi$	Maximum RHIC Cryogenic System Operating Pressure
$S := 14200 \cdot psi$	Maximum Allowable Stress, TP304L SST, A-269. Section II, Part D, p86
$S_n := S$ $\quad S_v := S$	Allowable Stress for nozzle and vessel, both are the same.
$f_{r1} := 1$ $\quad f_{r2} := 1$	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)
$leg := 0.06 \cdot in$	0.06" fillet on inside and outside of vessel, Fig UW-16.1 (i)
$c := 0 \cdot in$	No corrosion allowance

Comon calculations:

Actual t_1 and t_2 dimensions	$t_1 := 0.7 \cdot leg$	$t_2 := t_1$	$t_1 = 0.042 \cdot in$
A_{41} and A_{43} = Area available in weld	$A41 := leg^2 \cdot f_{r2}$	$A43 := A41$	$A41 = 0.004 \cdot in^2$
A5 and A42 = 0 (from geometry of weld)		$A5 := 0 \cdot in^2$	$A42 := 0 \cdot in^2$
Fillet weld Shear	$\tau_w := 0.49 \cdot S_n$		$\tau_w = 6958 \cdot psi$
Nozzle wall shear	$\tau_n := 0.7 \cdot S_n$		$\tau_n = 9940 \cdot psi$

User defined functions

Cicumferential Stress, UG-27(c)(1)- $\quad t_{calc}(D,T) := \dfrac{P \cdot \left(\dfrac{D}{2} - T\right)}{S \cdot E - 0.6 \cdot P}$

Area of Reinforcement Fig. UG-37.1- $\quad A(D,Tr,Tn) := D \cdot Tr \cdot F + 2 \cdot Tn \cdot Tr \cdot F \cdot \left(1 - f_{r1}\right)$

$$A_{1a}(T,Tr,Tn) := 2 \cdot (T + Tn) \cdot \left(E_1 \cdot T - F \cdot Tr\right) - 2 \cdot Tn \cdot \left(E_1 \cdot T - F \cdot Tr\right) \cdot \left(1 - f_{r1}\right)$$

$$A_{1b}(D,T,Tr,Tn) := D \cdot \left(E_1 \cdot T - F \cdot Tr\right) - 2 \cdot Tn \cdot \left(E_1 \cdot T - F \cdot Tr\right) \cdot \left(1 - f_{r1}\right)$$

$$A_{2a}(T,Tn,Trn) := 5 \cdot (Tn - Trn) \cdot f_{r2} \cdot T$$

$$A_{2b}(Tn,Trn) := 5 \cdot (Tn - Trn) \cdot f_{r2} \cdot Tn$$

$$A_3(h,Tn) := 2 \cdot (Tn - c) \cdot f_{r2} \cdot h$$

Strength of Connection Elements:

$$F_{weld}(Dn) := \frac{\pi}{2} \cdot Dn \cdot leg \cdot \tau_w$$

$$F_{wall}(D,Dn,Tn) := \frac{\pi}{2} \cdot \left(\frac{Dn + D}{2}\right) \cdot Tn \cdot \tau_n$$

Calculation 3.1 - Helium Supply Feedthrough. (see Dwg 34015000 & 34015026 for details)

Shell Dimensions	Nozzle Dimensions	
$D := 8 \cdot in$	$D_n := 0.5 \cdot in$	Outer diameter
$t := 0.12 \cdot in$	$t_n := 0.035 \cdot in$	Wall thickness

Finished diameter of circular opening	$d := D_n - 2 \cdot t_n$	$d = 0.43 \cdot in$
Required wall thickness shell	$t_r := t_{calc}(D, t)$	$t_r = 0.076 \cdot in$
Required wall thickness nozzle	$t_{rn} := t_{calc}(D_n, t_n)$	$t_{rn} = 0.004 \cdot in$

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

t_{min} = lesser of .75" or t of thinner part	$t_{min} := t_n$		$t_{min} = 0.035 \cdot in$
t_1 and t2 > smaller of .25" or .7*t_{min}	$t_1 = 0.042 \cdot in$	>	$0.7 \cdot t_{min} = 0.025 \cdot in$
$t_1 + t_2 > 1.25 * T_{min}$	$t_1 + t_2 = 0.084 \cdot in$	>	$1.25 \cdot t_{min} = 0.044 \cdot in$

Cover weld is satisfactory

Area of reinforcement required $\quad A_{req} := A(d, t_r, t_n) \quad A_{req} = 0.033 \cdot in^2$

Area of reinforcement available

A1 = Larger of the following: $\quad A_{1a}(t, t_r, t_n) = 0.014 \cdot in^2 \quad A_{1b}(d, t, t_r, t_n) = 0.019 \cdot in^2$

$A1 := A_{1b}(d, t, t_r, t_n)$

A2 = Smaller of the following: $\quad A_{2a}(t, t_n, t_{rn}) = 0.018 \cdot in^2 \quad A_{2b}(t_n, t_{rn}) = 0.005 \cdot in^2$

$A2 := A_{2b}(t_n, t_{rn})$

h = smaller of the following: $\quad 2.5 \cdot t = 0.3 \cdot in \quad 2.5 \cdot t_n = 0.088 \cdot in$

$h := 2.5 \cdot t_n$

A3 = The following: $\quad A_3(h, t_n) = 0.006 \cdot in^2$

$A3 := A_3(h, t_n)$

Total area available $\quad A_{total} := A1 + A2 + A3 + A41 + A43 \quad A_{total} = 0.038 \cdot in^2$

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

Calculate strength of reinforcement UG-41.1 (a)

Total Weld Load	$W := \left[A_{req} - (d - 2 \cdot t_n) \cdot (E_1 \cdot t - F \cdot t_r)\right] \cdot S_v$	$W = 239 \cdot lbf$
Path 1-1	$W_{11} := (A2 + A5 + A41 + A42) \cdot S_v$	$W_{11} = 128 \cdot lbf$
Path 2-2	$W_{22} := (A2 + A3 + A41 + A43 + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$	$W_{22} = 385 \cdot lbf$

Check strength paths

$$F_{weld}(D_n) = 328 \cdot lbf$$

$$F_{wall}(d, D_n, t_n) = 254 \cdot lbf$$

Path 1-1	$F_{11} := F_{weld}(D_n) + F_{wall}(d, D_n, t_n)$	$F_{11} = 582 \cdot lbf$
Path 2-2	$F_{22} := 2 \cdot F_{weld}(D_n)$	$F_{22} = 656 \cdot lbf$

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	Nozzle Dimensions	
	$D := 8 \cdot in$	$D_n := 0.75 \cdot in$	Outer diameter
	$t := 0.12 \cdot in$	$t_n := 0.035 \cdot in$	Wall thickness

Finished diameter of circular opening	$d := D_n - 2 \cdot t_n$	$d = 0.68 \cdot in$
Required wall thickness shell	$t_r := t_{calc}(D, t)$	$t_r = 0.076 \cdot in$
Required wall thickness nozzle	$t_{rn} := t_{calc}(D_n, t_n)$	$t_{rn} = 0.007 \cdot in$

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

t_{min} = lesser of .75" or t of thinner part	$t_{min} := t_n$		$t_{min} = 0.035 \cdot in$
t_1 and t2 > smaller of .25" or .7*t_{min}	$t_1 = 0.042 \cdot in$	>	$0.7 \cdot t_{min} = 0.025 \cdot in$
$t_1 + t_2 > 1.25 * T_{min}$	$t_1 + t_2 = 0.084 \cdot in$	>	$1.25 \cdot t_{min} = 0.044 \cdot in$

Cover weld is satisfactory

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

Area of reinforcement available

A1 = Larger of the following: $\quad A_{1a}(t, t_r, t_n) = 0.014 \cdot in^2 \quad A_{1b}(d, t, t_r, t_n) = 0.03 \cdot in^2$

$A1 := A_{1b}(d, t, t_r, t_n)$

A2 = Smaller of the following: $\quad A_{2a}(t, t_n, t_{rn}) = 0.017 \cdot in^2 \quad A_{2b}(t_n, t_{rn}) = 0.005 \cdot in^2$

$A2 := A_{2b}(t_n, t_{rn})$

h = smaller of the following: $\quad 2.5 \cdot t = 0.3 \cdot in \quad 2.5 \cdot t_n = 0.088 \cdot in$

$h := 2.5 \cdot t_n$

A3 = The following: $\quad A_3(h, t_n) = 0.006 \cdot in^2$

$A3 := A_3(h, t_n)$

Total area available $\quad A_{total} := A1 + A2 + A3 + A41 + A43 \quad A_{total} = 0.048 \cdot in^2$

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

Calculate strength of reinforcement UG-41.1 (a)

Total Weld Load	$W := \left[A_{req} - (d - 2 \cdot t_n) \cdot (E_1 \cdot t - F \cdot t_r)\right] \cdot S_v$	$W = 353 \cdot lbf$
Path 1-1	$W_{11} := (A2 + A5 + A41 + A42) \cdot S_v$	$W_{11} = 122 \cdot lbf$
Path 2-2	$W_{22} := (A2 + A3 + A41 + A43 + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$	$W_{22} = 379 \cdot lbf$

Check strength paths

$F_{weld}(D_n) = 492 \cdot lbf$

$F_{wall}(d, D_n, t_n) = 391 \cdot lbf$

Path 1-1	$F_{11} := F_{weld}(D_n) + F_{wall}(d, D_n, t_n)$	$F_{11} = 883 \cdot lbf$
Path 2-2	$F_{22} := 2 \cdot F_{weld}(D_n)$	$F_{22} = 984 \cdot lbf$

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	Nozzle Dimensions	
$D := 8 \cdot in$	$D_n := 1.5 \cdot in$	Outer diameter
$t := 0.12 \cdot in$	$t_n := 0.049 \cdot in$	Wall thickness

Finished diameter of circular opening	$d := D_n - 2 \cdot t_n$	$d = 1.402 \cdot in$
Required wall thickness shell	$t_r := t_{calc}(D, t)$	$t_r = 0.076 \cdot in$
Required wall thickness nozzle	$t_{rn} := t_{calc}(D_n, t_n)$	$t_{rn} = 0.014 \cdot in$

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

t_{min} = lesser of .75" or t of thinner part	$t_{min} := t_n$		$t_{min} = 0.049 \cdot in$
t_1 and t2 > smaller of .25" or .7*t_{min}	$t_1 = 0.042 \cdot in$	>	$0.7 \cdot t_{min} = 0.034 \cdot in$
$t_1 + t_2 > 1.25 * T_{min}$	$t_1 + t_2 = 0.084 \cdot in$	>	$1.25 \cdot t_{min} = 0.061 \cdot in$

Cover weld is satisfactory

Area of reinforcement required $\quad A_{req} := A(d, t_r, t_n) \quad A_{req} = 0.107 \cdot in^2$

Area of reinforcement available

A1 = Larger of the following: $\quad A_{1a}(t, t_r, t_n) = 0.015 \cdot in^2 \quad A_{1b}(d, t, t_r, t_n) = 0.062 \cdot in^2$

$A1 := A_{1b}(d, t, t_r, t_n)$

A2 = Smaller of the following: $\quad A_{2a}(t, t_n, t_{rn}) = 0.021 \cdot in^2 \quad A_{2b}(t_n, t_{rn}) = 0.009 \cdot in^2$

$A2 := A_{2b}(t_n, t_{rn})$

h = smaller of the following: $\quad 2.5 \cdot t = 0.3 \cdot in \quad 2.5 \cdot t_n = 0.123 \cdot in$

$h := 2.5 \cdot t_n$

A3 = The following: $\quad A_3(h, t_n) = 0.012 \cdot in^2$

$A3 := A_3(h, t_n)$

Total area available $\quad A_{total} := A1 + A2 + A3 + A41 + A43 \quad A_{total} = 0.089 \cdot in^2$

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

Calculate strength of reinforcement UG-41.1 (a)

Total Weld Load	$W := \left[A_{req} - (d - 2 \cdot t_n) \cdot (E_1 \cdot t - F \cdot t_r)\right] \cdot S_v$	$W = 699 \cdot lbf$
Path 1-1	$W_{11} := (A2 + A5 + A41 + A42) \cdot S_v$	$W_{11} = 174 \cdot lbf$
Path 2-2	$W_{22} := (A2 + A3 + A41 + A43 + 2 \cdot t_n \cdot t \cdot f_{r1}) \cdot S_v$	$W_{22} = 562 \cdot lbf$

Check strength paths

$$F_{weld}(D_n) = 984 \cdot lbf$$

$$F_{wall}(d, D_n, t_n) = 1110 \cdot lbf$$

Path 1-1	$F_{11} := F_{weld}(D_n) + F_{wall}(d, D_n, t_n)$	$F_{11} = 2094 \cdot lbf$
Path 2-2	$F_{22} := 2 \cdot F_{weld}(D_n)$	$F_{22} = 1967 \cdot lbf$

Part meets code requirements. - All paths are stonger than the required strength

SECTION 4.0 - Strength of Nozzles with Grove and Covering Fillet Welds

$P := 275 \cdot psi$	Maximum RHIC Cryogenic System Operating Pressure
$S := 14200 \cdot psi$	Maximum Allowable Stress, 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)
$S_n := S \quad S_v := S$	Allowable Stress for nozzle and vessel, both are the same.
$f_{r1} := 1 \quad f_{r2} := 1$	Strength reduction factors equal unity because materials are identical
$E := 1.0$	Joint efficiency for required wall thickness (from UG-37 (a), p47)
$F := 1$	Correction factor, 1 for all applications (p47)
$E_1 := 1$	Opening in solid plate
$c := 0 \cdot in$	No corrosion allowance

User defined functions:

Cicumferential Stress, UG-27(c)(1)-

$$t_{calc}(D,T) := \frac{P \cdot \left(\frac{D}{2} - T\right)}{S \cdot E - 0.6 \cdot P}$$

Area of Reinforcement Fig. UG-37.1-

$$A(D, Tr, Tn) := D \cdot Tr \cdot F + 2 \cdot Tn \cdot Tr \cdot F \cdot \left(1 - f_{r1}\right)$$

$$A_{1a}(T, Tr, Tn) := 2 \cdot (T + Tn) \cdot \left(E_1 \cdot T - F \cdot Tr\right) - 2 \cdot Tn \cdot \left(E_1 \cdot T - F \cdot Tr\right) \cdot \left(1 - f_{r1}\right)$$

$$A_{1b}(D, T, Tr, Tn) := D \cdot \left(E_1 \cdot T - F \cdot Tr\right) - 2 \cdot Tn \cdot \left(E_1 \cdot T - F \cdot Tr\right) \cdot \left(1 - f_{r1}\right)$$

$$A_{2a}(T, Tn, Trn) := 5 \cdot (Tn - Trn) \cdot f_{r2} \cdot T$$

$$A_{2b}(Tn, Trn) := 5 \cdot (Tn - Trn) \cdot f_{r2} \cdot Tn$$

$$A_3(h, Tn) := 2 \cdot (Tn - c) \cdot f_{r2} \cdot h$$

Calculation 4.1 - Manifold Feedthrough Recooler. (see Dwg 34015000, 34015010, &34015002 for details)

Shell Dimensions	Nozzle Dimensions	
$D := 8 \cdot in$	$D_n := 1.625 \cdot in$	Outer diameter
$t := 0.12 \cdot in$	$t_n := 0.120 \cdot in$	Wall thickness
$leg := 0.13 \cdot in$		Fillet cover-weld size

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

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

Required wall thickness nozzle $\quad t_{rn} := t_{calc}(D_n, t_n) \quad t_{rn} = 0.014 \cdot in$

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

t_{min} = lesser of .75" or t of thinner part $\quad t_{min} := t_n \quad t_{min} = 0.12 \cdot in$

t_c > smaller of .25" or .7*t_{min} $\quad t_c := 0.7 \cdot leg \quad t_c = 0.091 \cdot in > 0.7 \cdot t_{min} = 0.084 \cdot in$

Cover weld is satisfactory

Area of reinforcement required $\quad A_{req} := A(d, t_r, t_n) \quad A_{req} = 0.105 \cdot in^2$

Area of reinforcement available

A1 = Larger of the following: $\quad A_{1a}(t, t_r, t_n) = 0.021 \cdot in^2 \quad A_{1b}(d, t, t_r, t_n) = 0.061 \cdot in^2$

$A1 := A_{1b}(d, t, t_r, t_n)$

A2 = Smaller of the following: $\quad A_{2a}(t, t_n, t_{rn}) = 0.064 \cdot in^2 \quad A_{2b}(t_n, t_{rn}) = 0.064 \cdot in^2$

$A2 := A_{2b}(t_n, t_{rn})$

h = smaller of the following: $\quad 2.5 \cdot t = 0.3 \cdot in \quad 2.5 \cdot t_n = 0.3 \cdot in$

$h := 2.5 \cdot t_n$

A3 = The following: $\quad A3 := A_3(h, t_n) \quad A3 = 0.072 \cdot in^2$

A41 = The following $\quad A41 := leg^2 \cdot f_{r2} \quad A41 = 0.017 \cdot in^2$

Total area available $\quad A_{total} := A1 + A2 + A3 + A41 \quad A_{total} = 0.214 \cdot in^2$

Since $A_{total} > A_{req}$ 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	
$D := 2.25 \cdot in$	$D_n := 1.515 \cdot in$	Outer diameter
$t := 0.065 \cdot in$	$t_n := 0.065 \cdot in$	Wall thickness
$leg := 0.07 \cdot in$		Fillet cover-weld size

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

Required wall thickness shell $\quad t_r := t_{calc}(D, t) \quad t_r = 0.021 \cdot in$

Required wall thickness nozzle $\quad t_{rn} := t_{calc}(D_n, t_n) \quad t_{rn} = 0.014 \cdot in$

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

t_{min} = lesser of .75" or t of thinner part $\quad t_{min} := t_n \quad t_{min} = 0.065 \cdot in$

t_c > smaller of .25" or .7*t_{min} $\quad t_c := 0.7 \cdot leg \quad t_c = 0.049 \cdot in > 0.7 \cdot t_{min} = 0.045 \cdot in$

Cover weld is satisfactory

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

Area of reinforcement available

A1 = Larger of the following: $\quad A_{1a}(t, t_r, t_n) = 0.011 \cdot in^2 \quad A_{1b}(d, t, t_r, t_n) = 0.061 \cdot in^2$

$A1 := A_{1b}(d, t, t_r, t_n)$

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

$A2 := A_{2b}(t_n, t_{rn})$

h = smaller of the following: $\quad 2.5 \cdot t = 0.163 \cdot in \quad 2.5 \cdot t_n = 0.163 \cdot in$

$h := 2.5 \cdot t_n$

A3 = The following: $\quad A3 := A_3(h, t_n) \quad A3 = 0.021 \cdot in^2$

A41 = The following: $\quad A41 := leg^2 \cdot f_{r2} \quad A41 = 0.005 \cdot in^2$

Total area available $\quad A_{total} := A1 + A2 + A3 + A41 \quad A_{total} = 0.104 \cdot in^2$

Since $A_{total} > A_{req}$ 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	Nozzle Dimensions	
$D := 2.25 \cdot in$	$D_n := 0.563 \cdot in$	Outer diameter
$t := 0.065 \cdot in$	$t_n := 0.065 \cdot in$	Wall thickness
$leg := 0.07 \cdot in$		Fillet cover-weld size

Finished diameter of circular opening	$d := D_n - 2 \cdot t_n$	$d = 0.433 \cdot in$
Required wall thickness shell	$t_r := t_{calc}(D, t)$	$t_r = 0.021 \cdot in$
Required wall thickness nozzle	$t_{rn} := t_{calc}(D_n, t_n)$	$t_{rn} = 0.004 \cdot in$

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

t_{min} = lesser of .75" or t of thinner part $t_{min} := t_n$ $t_{min} = 0.065 \cdot in$

t_c > smaller of .25" or .7*t_{min} $t_c := 0.7 \cdot leg$ $t_c = 0.049 \cdot in > 0.7 \cdot t_{min} = 0.045 \cdot in$

Cover weld is satisfactory

Area of reinforcement required $A_{req} := A(d, t_r, t_n)$ $A_{req} = 0.009 \cdot in^2$

Area of reinforcement available

A1 = Larger of the following: $A_{1a}(t, t_r, t_n) = 0.011 \cdot in^2$ $A_{1b}(d, t, t_r, t_n) = 0.019 \cdot in^2$

$A1 := A_{1b}(d, t, t_r, t_n)$

A2 = Smaller of the following: $A_{2a}(t, t_n, t_{rn}) = 0.02 \cdot in^2$ $A_{2b}(t_n, t_{rn}) = 0.02 \cdot in^2$

$A2 := A_{2b}(t_n, t_{rn})$

h = smaller of the following: $2.5 \cdot t = 0.163 \cdot in$ $2.5 \cdot t_n = 0.163 \cdot in$

$h := 2.5 \cdot t_n$

A3 = The following: $A3 := A_3(h, t_n)$ $A3 = 0.021 \cdot in^2$

A41 = The following: $A41 := leg^2 \cdot f_{r2}$ $A41 = 0.005 \cdot in^2$

Total area available $A_{total} := A1 + A2 + A3 + A41$ $A_{total} = 0.065 \cdot in^2$

Since $A_{total} > A_{req}$ 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

$P := 275 \cdot psi$ Maximum RHIC Cryogenic System Operating Pressure

$S := 14200 \cdot psi$ 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 - $R(d,t) := \frac{d}{2} - t$

Cicumferential 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)- $t_l(d,t,e,s) := \frac{P \cdot R(d,t)}{2 \cdot s \cdot e + 0.4 \cdot P}$

From UG-53 Ligaments (b)

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

$d := 0.515 \cdot in$ Diameter of tube holes. Same for all configurations

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

$p := 1.07 \cdot in$ Hole Pitch

$Le := \frac{p - d}{p}$ $Le = 51.9 \cdot \%$

From UG-27 Thickness of Shells Under Internal Pressure

(b) $E := Le$ Joint efficiency equals ligament efficiency

$D_o := 2.25 \cdot in$ Design OD of Shell

$T_o := 0.065 \cdot in$ Design Wall thickness of Shell

$R := \frac{D_o}{2} - T_o$ $R = 1.06 \cdot in$ Inside radius of shell

(c)(1) Cicumferential Stress (Longitudinal Joints)

$t := \frac{P \cdot R}{S \cdot E - 0.6 \cdot P}$ $t = 0.04 \cdot in$

(c)(2) Longitudinal Stress (Circumferential Joints)

$t := \frac{P \cdot R}{2 \cdot S \cdot E + 0.4 \cdot P}$ $t = 0.02 \cdot in$

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