Valve Box Repair Mechanical Engineering

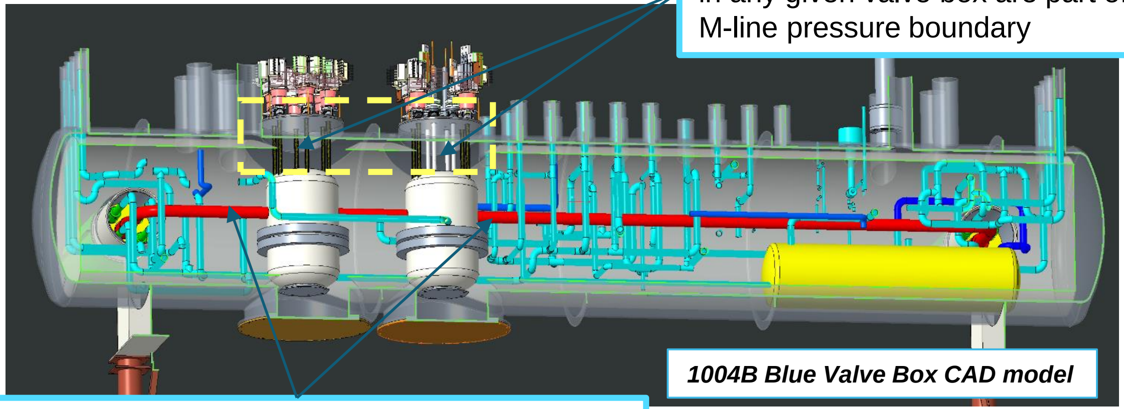
Russell Feder for the 1004B valve box repair engineering team

11/28/23

1004B Blue Valve Box

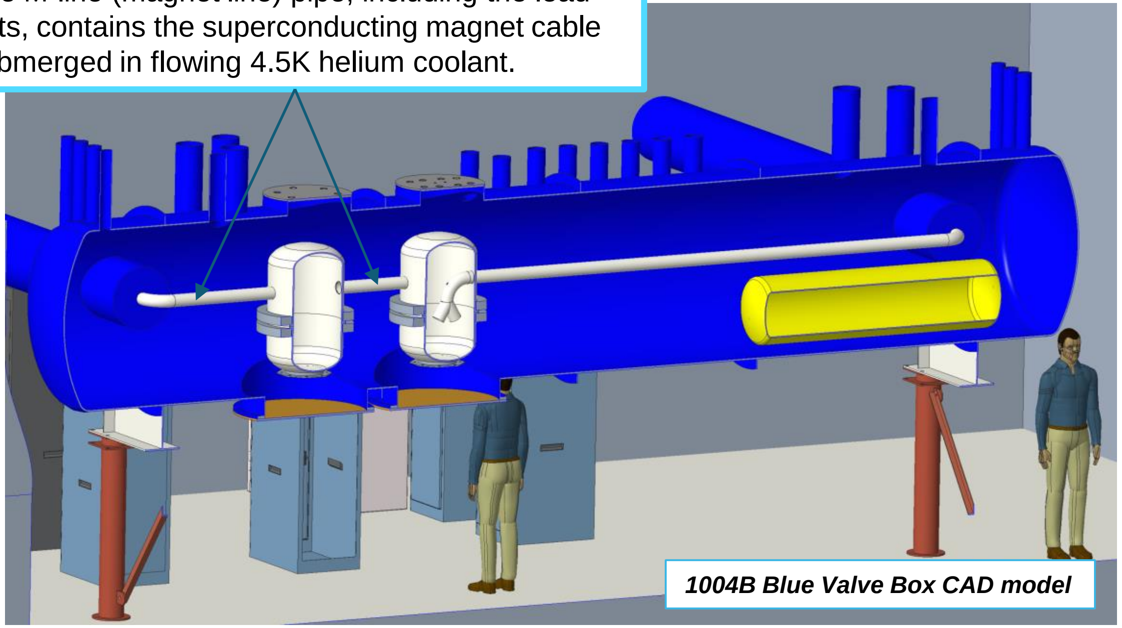
CAD models and drawings

All of the lead pot feedthrough tubes in any given valve box are part of the M-line pressure boundary



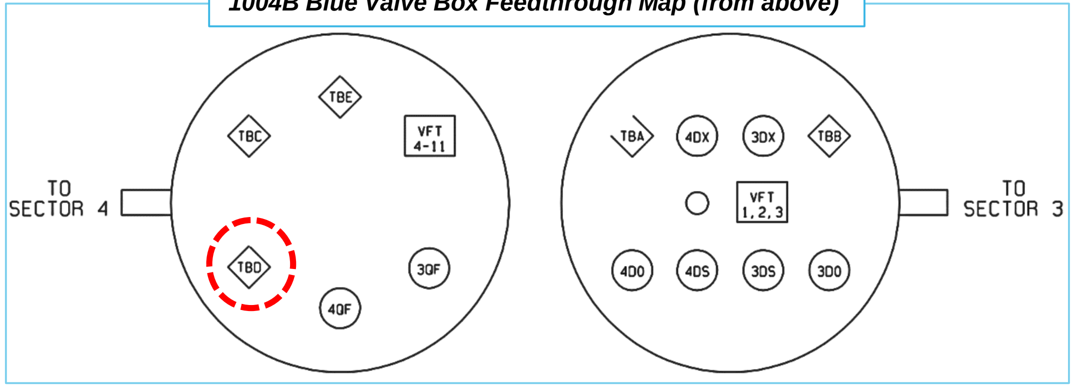
1004B Blue Valve Box CAD model

The M-line (magnet line) pipe, including the lead pots, contains the superconducting magnet cable submerged in flowing 4.5K helium coolant.

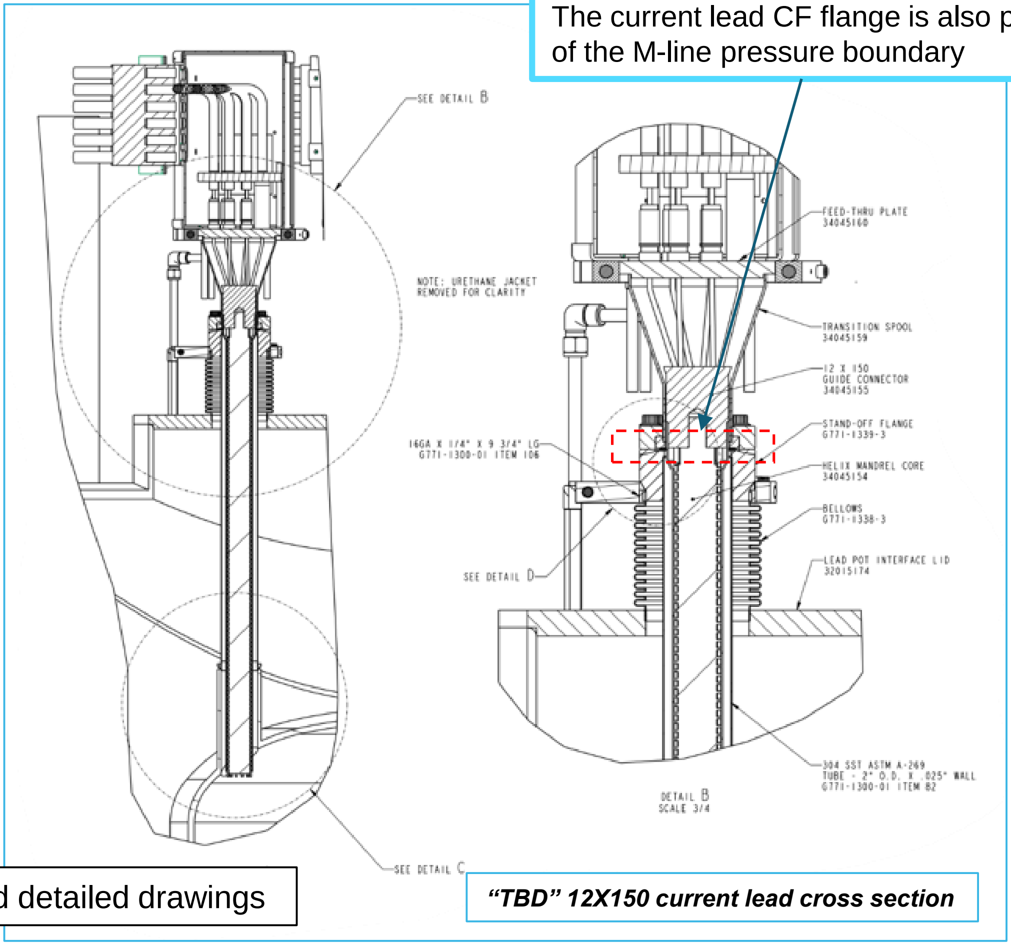


1004B Blue Valve Box CAD model

1004B Blue Valve Box Feedthrough Map (from above)



The current lead CF flange is also part of the M-line pressure boundary



"TBD" 12X150 current lead cross section

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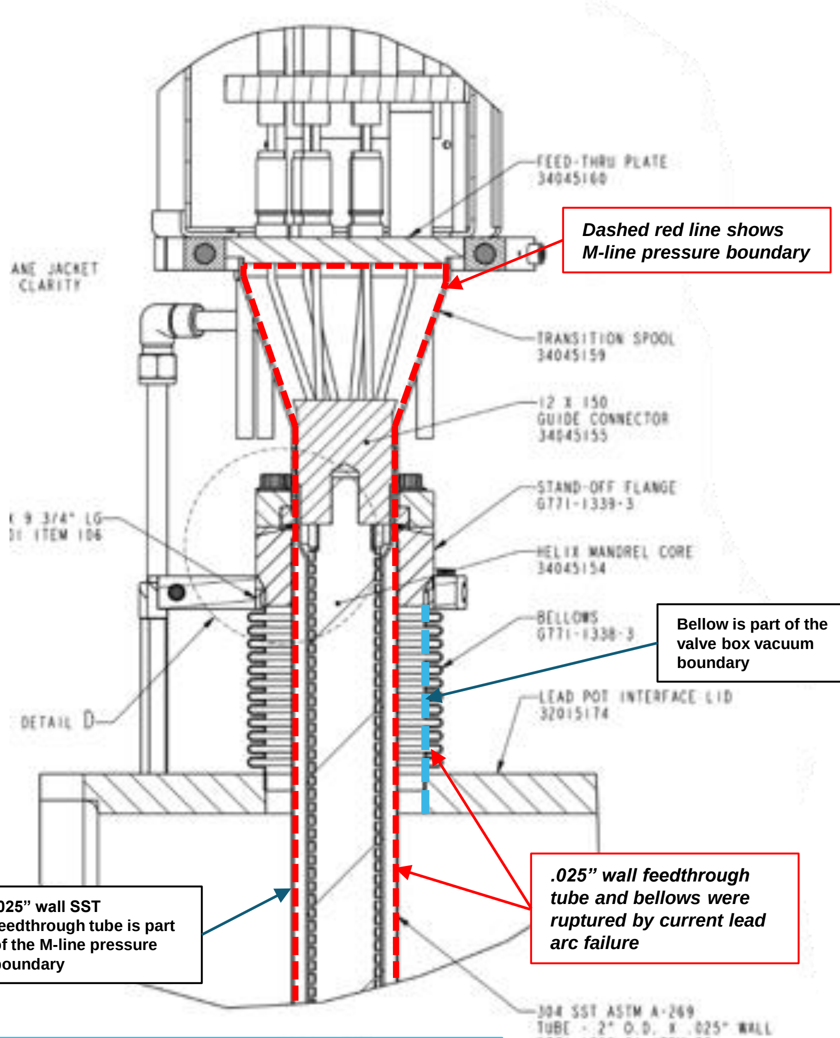
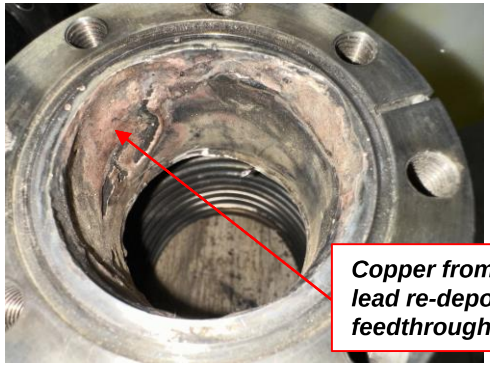
*Credit to Harlan Lovera for creating all of these CAD models and detailed drawings

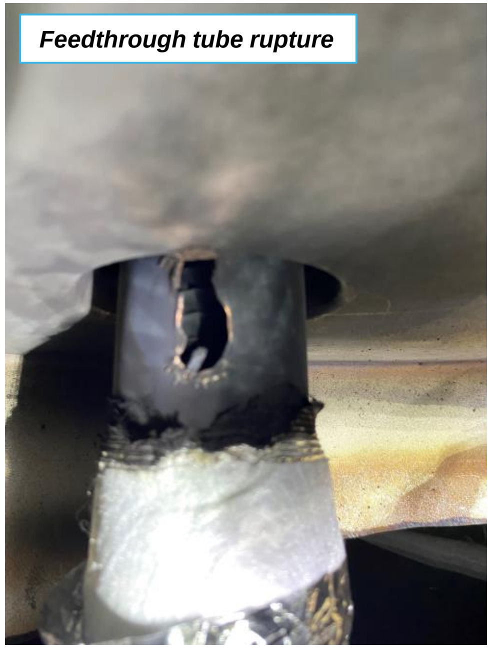
Lead pot “A” “TBD” feedthrough piping damage

This feedthrough is part of the M-line pressure boundary and the valve box pressure boundary



“TBD” 12X150 current lead cross section

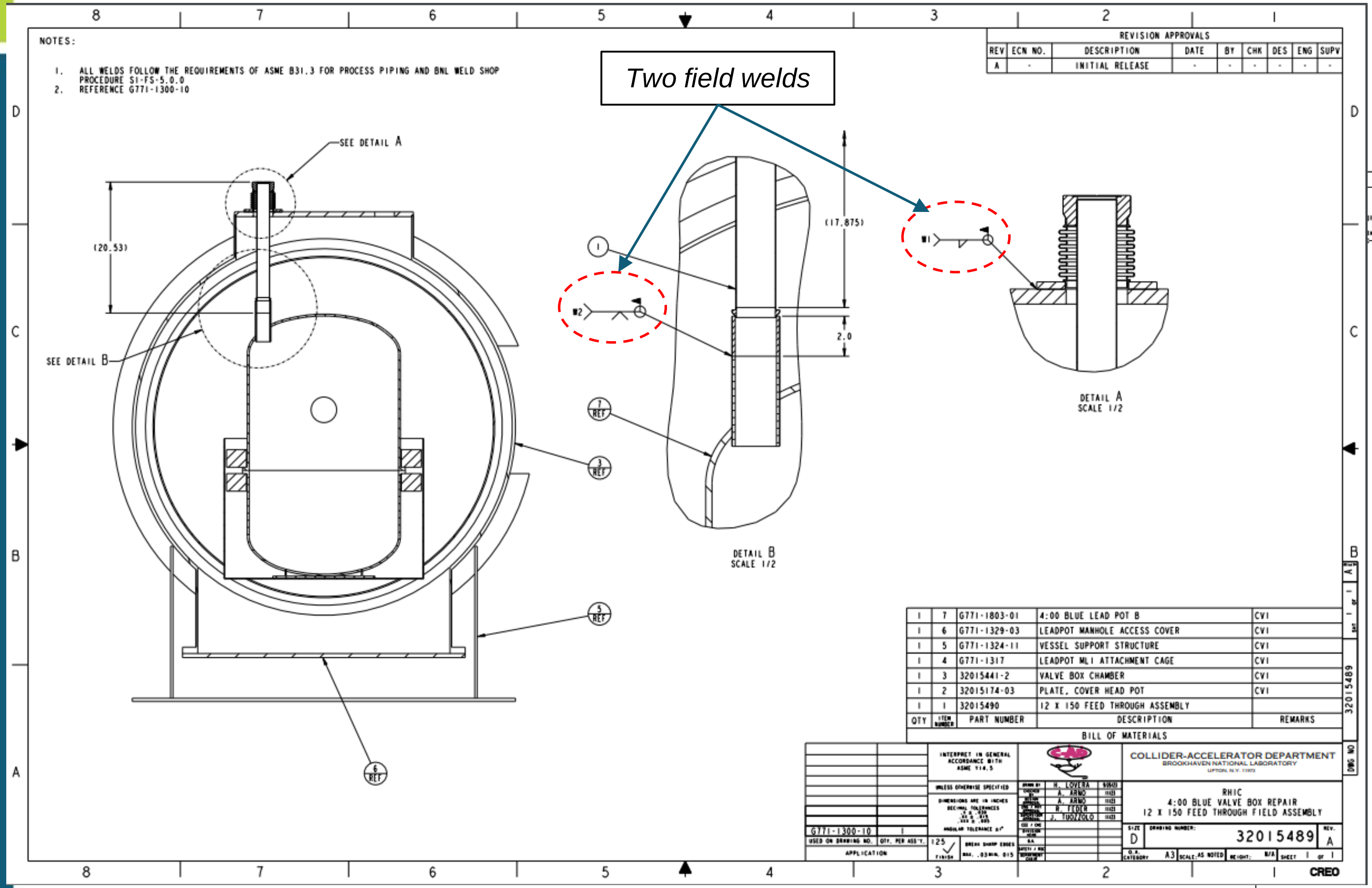


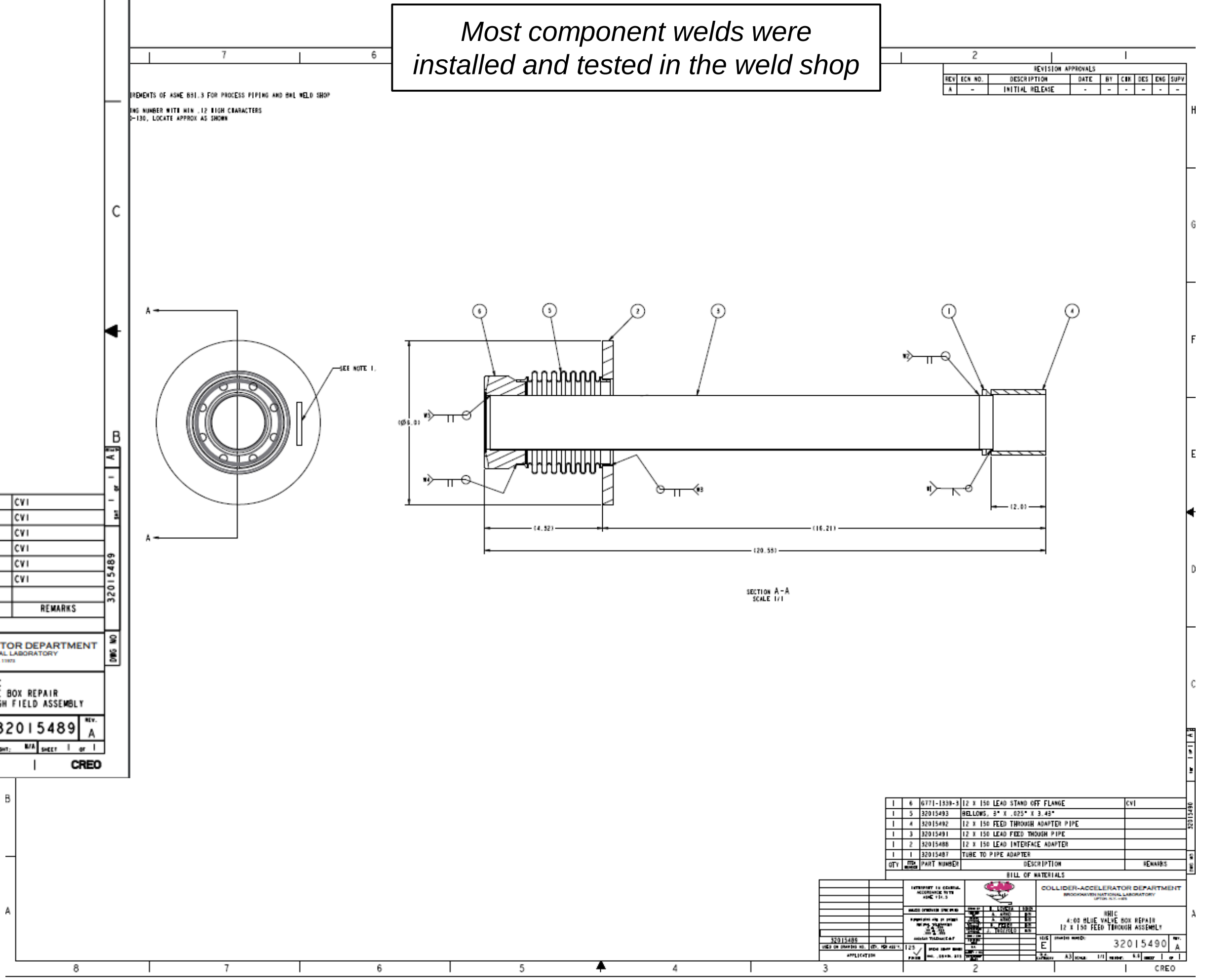


For more information on the causal analysis and electrical events that lead to this damage
→ Talks coming up next by Jon Sandberg, Chaofeng Mi, and John Escalier

Lead pot “A” “TBD” feedthrough repair design

- *Design and parts sourcing: Harlan Lovera and Richard Muscolino, CA-D engineering*
- *Parts sourcing and fabrication: The Cryo Group mechanical team*

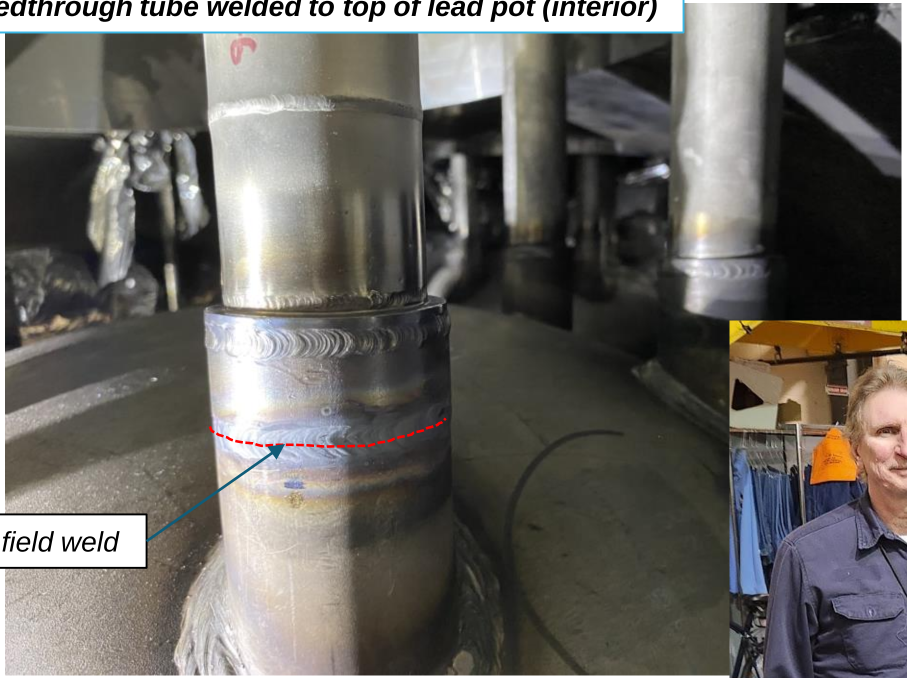




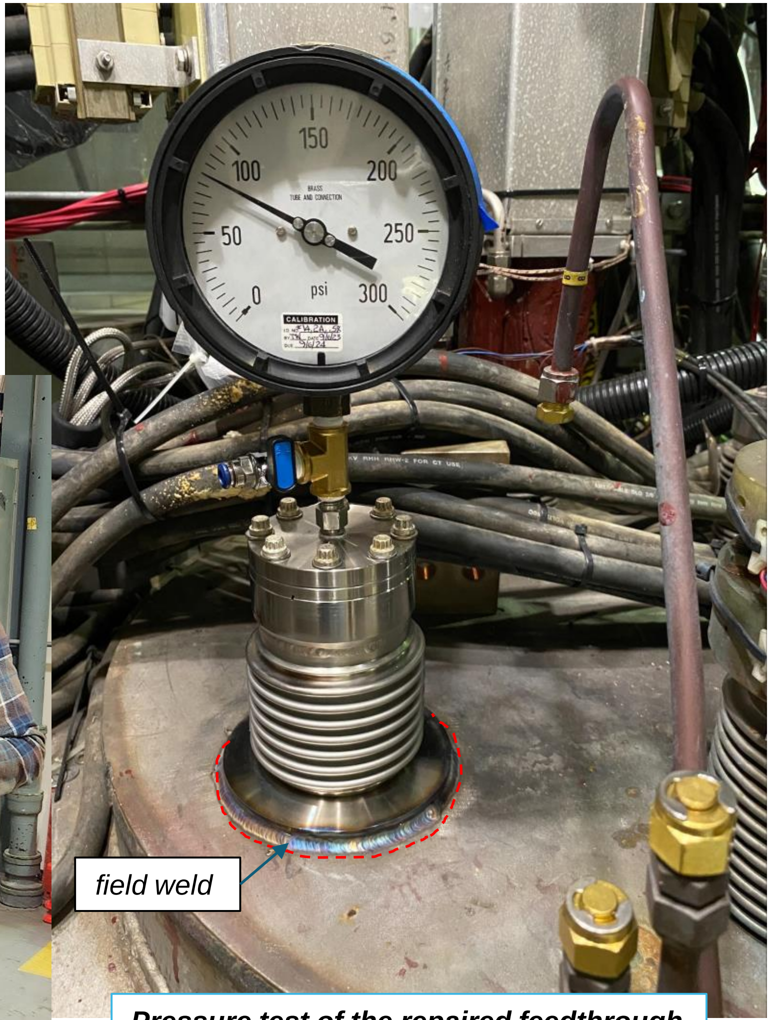
Lead pot “A” “TBD” feedthrough repair

Repair completed 11/18 with successful pressure test

Feedthrough tube welded to top of lead pot (interior)



The 1004B Blue Valve Box Entry and Repair Team
Tom Wozniak, Jeff Stewart, Nick Stivala



Pressure test of the repaired feedthrough
Tested to 8 atm, ~120 psi

M-Line Design and Test Pressure

- *Operating Pressure: 58 psi (4 bar)*
- *Spare 12X150 Current Lead and Repaired M-line Test pressure: 120 psi (8 bar)*
- *But…By design, M-line reliefs are set to 250 psi (17.2 bar)*
- *Only have one 12x150 spare → Protect fragile ceramic feedthroughs*
- *Need to reconcile this → Get written approval for variation before March, 2024 restart*

Than, Yatming (Roberto)
To: Feder, Russell; Weiss, Dan; Decker, Kenneth; Warkentien, Andreas F; Muscolino, Richard; Lehn, Robert D; Tuozzolo, Joseph E; Escallier, John; Mi, Chaofeng; Heitz, Erik

Design pressure is 18.7 atm differential (275 psid,260 psig)
Relief are set at 250 psig.

Note one of the rows, the bad formatting shifted the numbers.
20.6 bar = 300 psi

Table 3-8. Cryogenic System Pressure Ratings

RHIC operations 4 bar (58 psi)

Pressure (bar, absolute except as noted)

Sub-System	Nominal Oper.	Design Working (Max Diff)	Relief Valve Set (Gauge)	Pneu. Test -Piping (Gauge) (***FEA***)	Pneu. Test -Vessels (Gauge)
Magnet Loop	5.0 (73 psi)	18.7	17.7 (256 psi)	20.6 (300 psi)	23.4
Recooler Supply Header	6.0	18.7	17.7	20.6	23.4
Return (Cold) Header 1.3	18.7	17.7	20.6	23.4	
Utility Header	1.3	18.7	17.7	20.6	23.4
Heat Shield	15.0	18.7	17.7	20.6	23.4
Ambient Temp. Return	1.4	18.7	18.7	20.6	23.4
Main Compressor Suction	1.05	6.8	5.2	7.5	8.5
Main Compressor 1st Stage Disch.	4.0	6.8	6.8	7.5	8.5
Main Compressor Interstage	4.0	9.1	9.1	10.0	11.4
Main Compressor 2nd Stage Disch.	16.4	18.7	18.7	20.6	23.4

Since the 2011 loss of cooling water incident when several ceramic feedthroughs failed at or below relief valve pressure, we have never brought the M-line or the RUSH lines up to relief valve pressure for pressure checking any repairs or modifications like diodes repairs or DX taps, Sphenix taps, Snake removal/dummy install. Typically, we would go to about 8 atm and sniff all new welds.

Tuozzolo, Joseph E
To: Feder, Russell; Than, Yatming (Roberto)

Yeah, I have to talk to Ray. This could be a problem. We have reliefs set at the higher pressure. We are doing work on the pressure boundary and then not certifying the work to that level. Didn't know we were only testing to 8 atmos until now.

In practice we should be replacing all of our relief valves to the lower pressure. Issue is that in a major event where the compressors are lost the system could lose more Helium since it couldn't be driven into the tanks or liquified into the dewars as well.

Roberto any guess how much?

Than, Yatming (Roberto)
To: Tuozzolo, Joseph E; Feder, Russell

All the circuits have 250 psig reliefs.
But we only need to derate the M-line.
4/sextant x 6 x 2 = 48 x 6K = 288K

Option: Only derate 1 of 4
4 reliefs: Catastrophic failure of insulating vacuum in magnet cryostat
1 relief: Loss of power trapped volume: Only heat leak will build pressure.

For EIC we can do a dual reliefs where we set the lower value to be captured and piped back to central plant and to new ambient vaporizer then to tanks.
Lower relief at 8 atm, higher at 10 atm.

B31.3 Piping: 345.9 Alternative leak test: we are allowed if we 100% x-ray or ultrasonic exam for groove welds plus sensitive leak check with mass spec.; other welds types require Dye Penetrant.
Sensitive leak check is done at 2 atm-abs.
B31.3 B345.2.3 Special provisions for Testing: (c) Closure welds: In-Process-Examination, plus 100%X-ray or 100% ultrasonic.

Than, Yatming (Roberto)
To: Tuozzolo, Joseph E; Feder, Russell

Instrumentation and electrical feedthroughs are not part of the piping and pressure vessel code scope, but are the responsibility of the owner.
The current leads feedthroughs may leak but are not failing.

Tuozzolo, Joseph E
To: Than, Yatming (Roberto); Feder, Russell

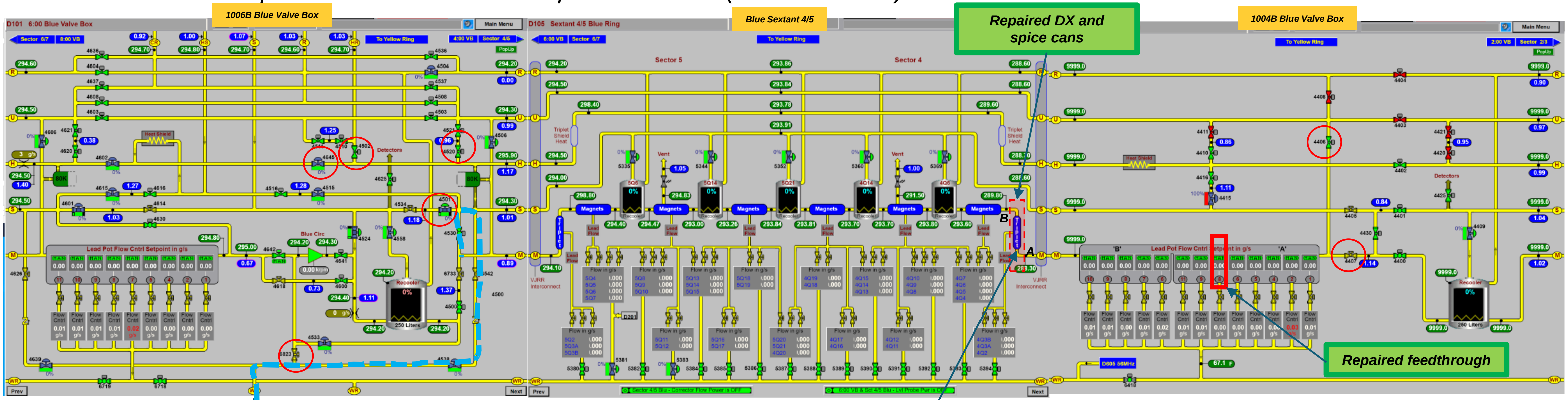
Thanks Roberto

Would like to complete the RHIC run with the present reliefs recognizing that there is a weak point at the feedthroughs and that repairs and replacements are not tested to relief pressure.

Joe

Final Pressure Test: M, S, and H-lines from the 1004B valve box to the 1006B valve box

- *Need to close all splice cans at 4:00 to test repairs at 1004B (and visa versa)*



Start Here: Warm Supply from tank farm for pressure test

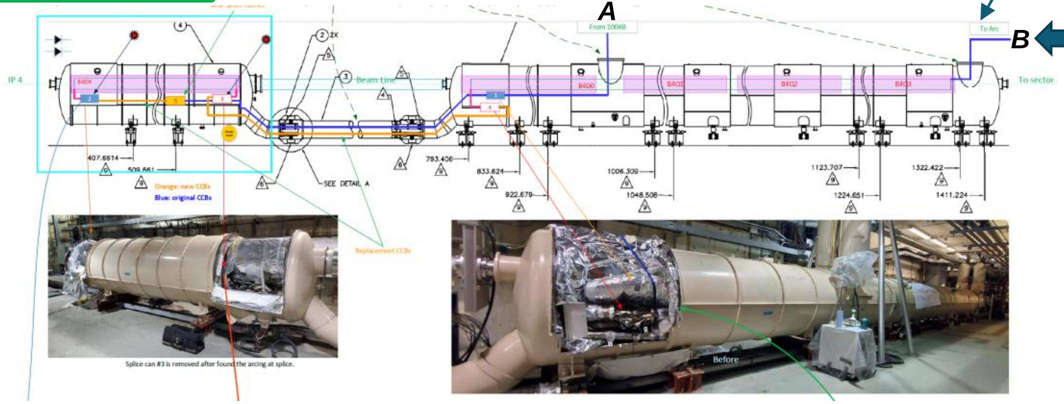
To/From 1004B

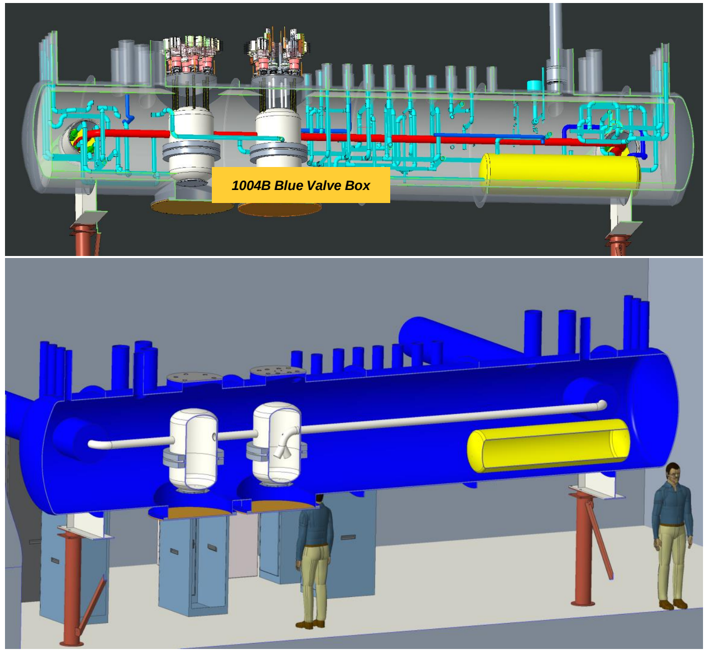
A

This is the 4:00 DX-D0-Triplet

B

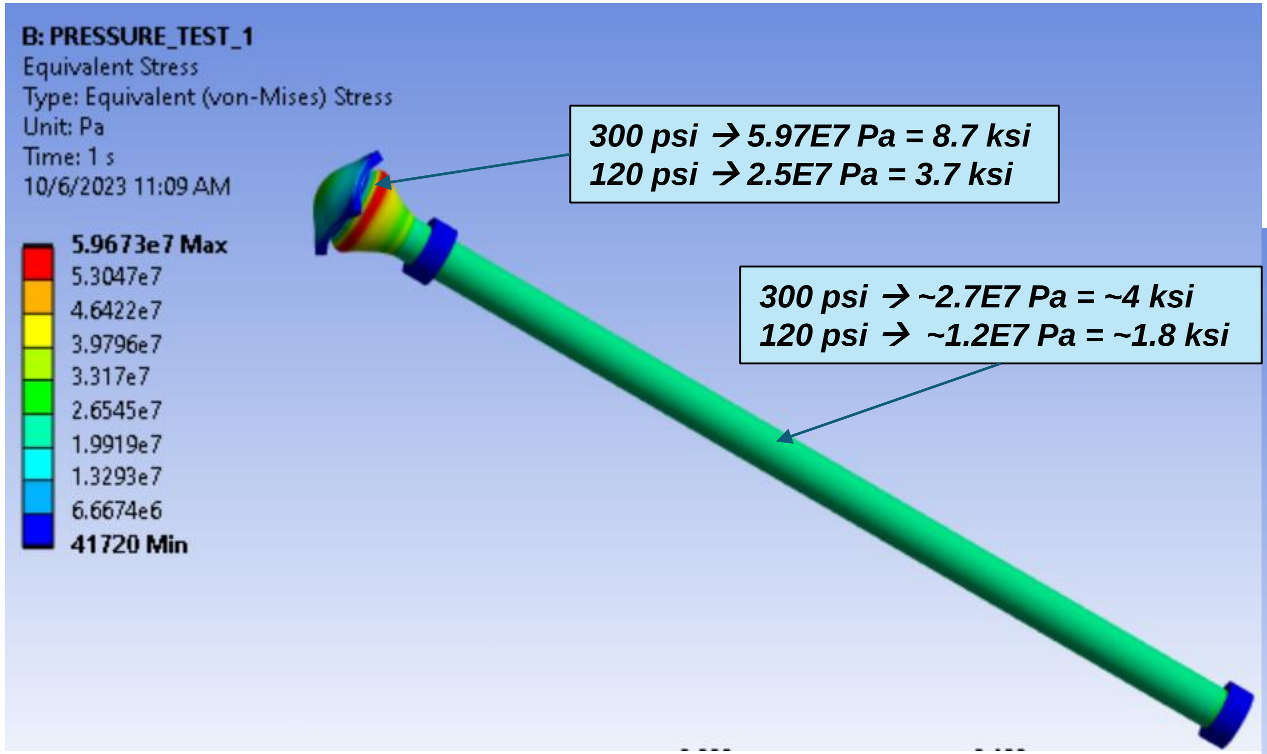
To/From Sextant 4/5

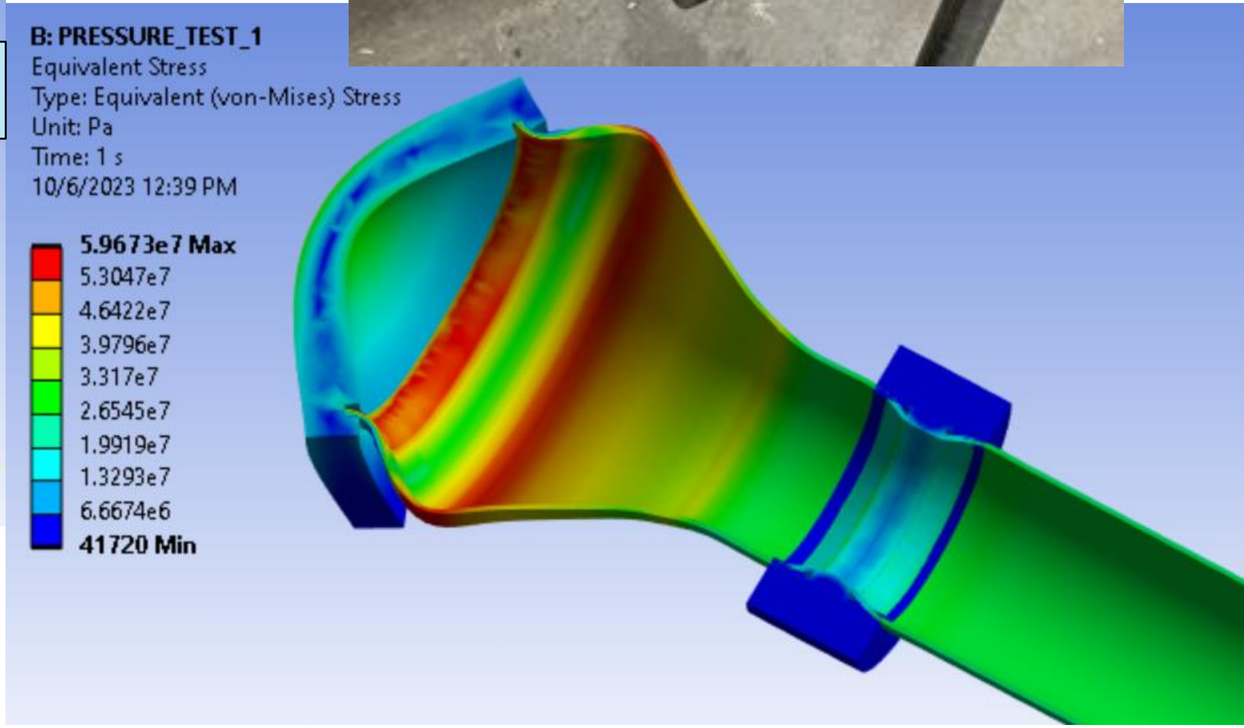




12X150 current lead and pressure test pipe FEA check

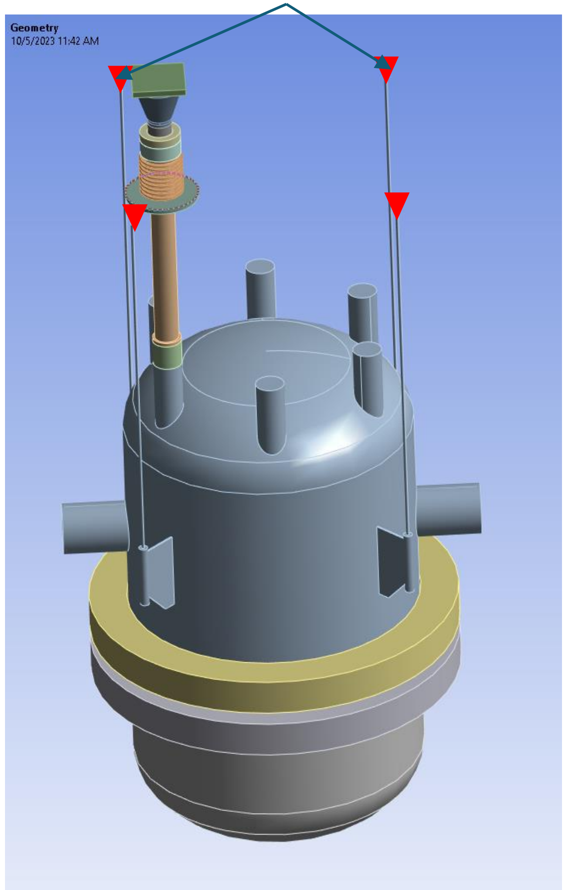
- *FEA at (A) 120 psi (8 atm) internal test pressure and at (B) 300 psi internal pressure*
- *M-line typically operates at 4 bar, 58 psi*
- *Allowable stress = 16,700 psi*

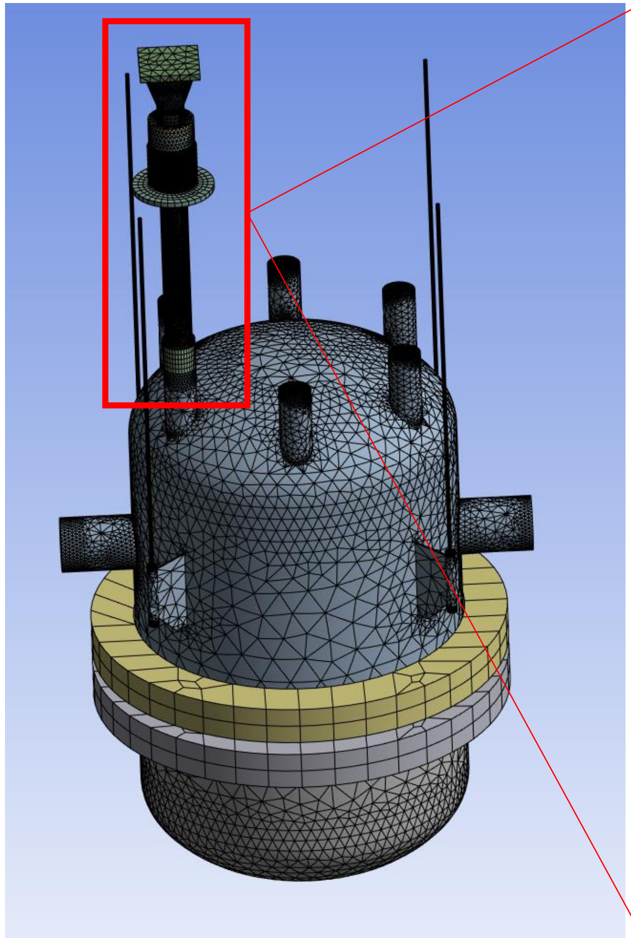


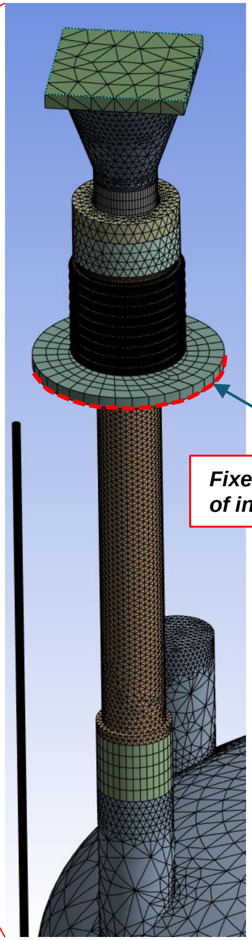


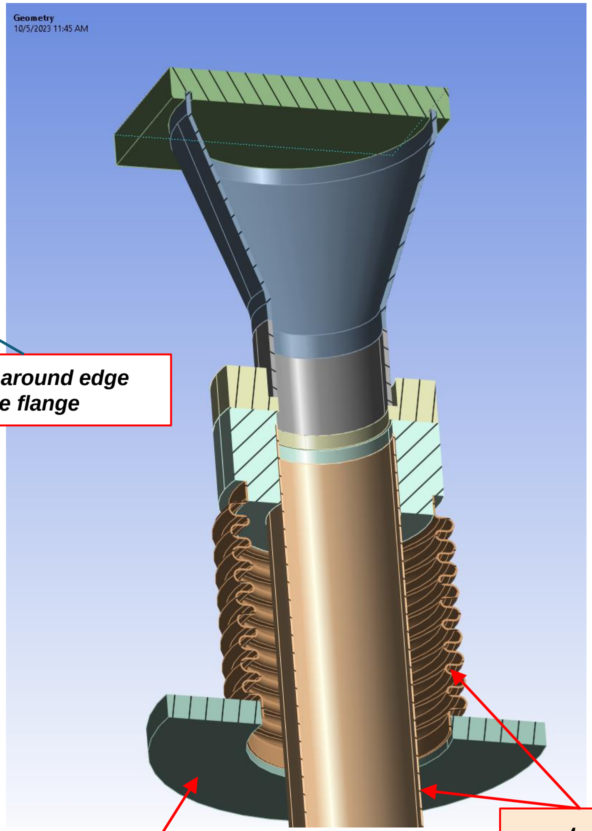
Lead Pot and 12X150 current lead FEA

- *Use FEA to verify performance of the lead pot and feedthrough design, and new interface welding flange*
- *Lead pots are suspended from inside of valve box with ¼” threaded rod. The gravity load is shared by threaded rod, feedthrough bellows, and M-line pipe stiffness. Not enough detail in this model to demonstrate all of that.*
- *Did not include contraction from 300K to 4K, assumed everything modeled is at the same temperature*









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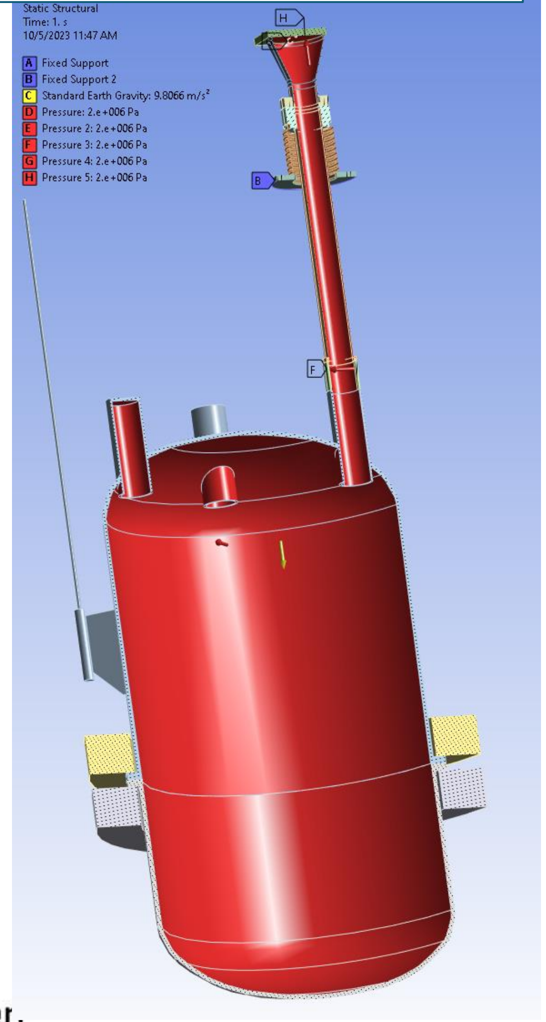
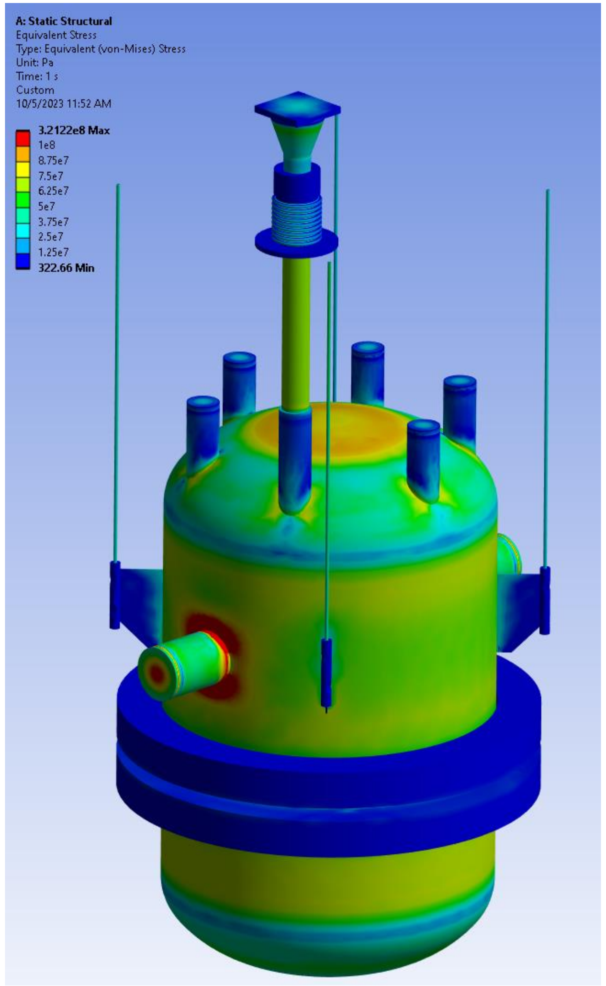
Lead Pot and 12X150 current lead FEA

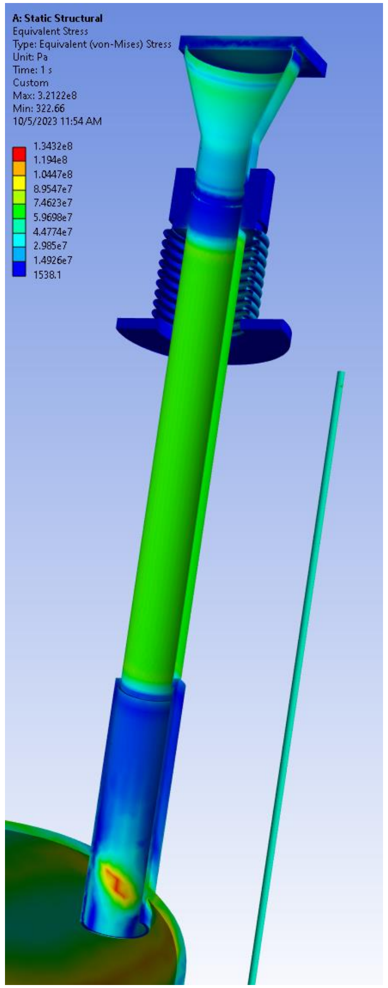
- *Stress around repaired feedthrough including the new weld interface flange are well below the allowable for the 300 psi internal pressure case. Normal operating pressure is 58 psi.*
- *Allowable stress: 16.7 ksi, 115 MPa*

Internal Pressure Applied = 300 psi = 2 MPa



VonMises Stress in tube = ~6E7 Pa = 8.7 ksi





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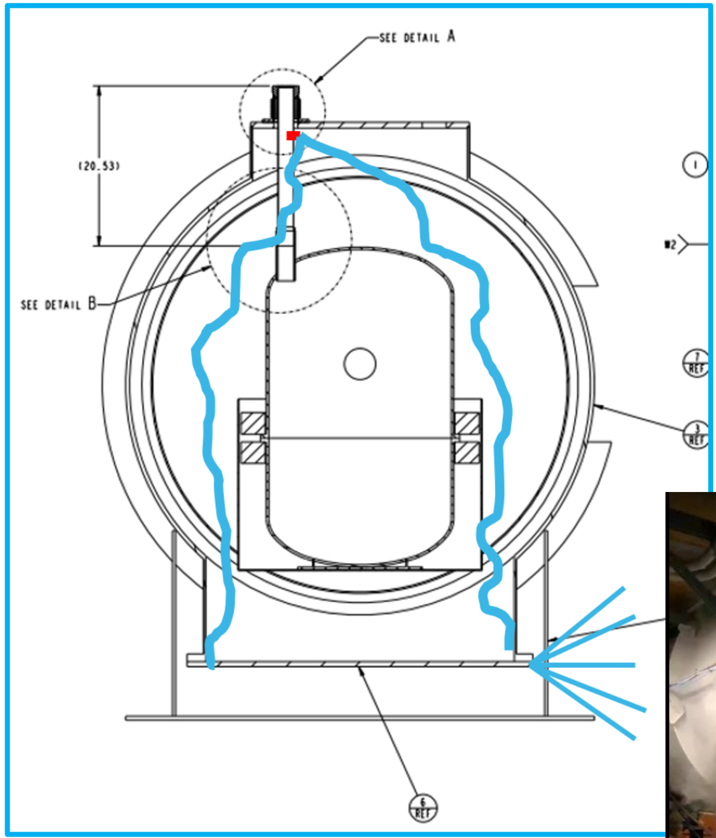
Valve Box Manhole Cover O-rings

- *O-ring froze and cracked in three places after inundation of cold helium from the feedthrough rupture above*
- *Despite the unexpected seal failure, we are not changing the design or O-ring material*

- 6.5mm OD manhole cover Viton o-ring froze, cracked, and leaked due to bath of very cold helium gushing from ruptured feedthrough
- We found three cracks of about 2 mm width in the o-ring
- This failure mode was not part of original ODH modeling…neither was the ruptured bellows
- Considered using silicone and we tested viton, buna-N and silicone dipped in LN2. All became brittle and cracked.
- Installing new viton o-rings
- For EIC, consider designing shroud or umbrella that diverts?
- With ASE update and service building ODH systems joining RHIC credited controls, don't need to upgrade.



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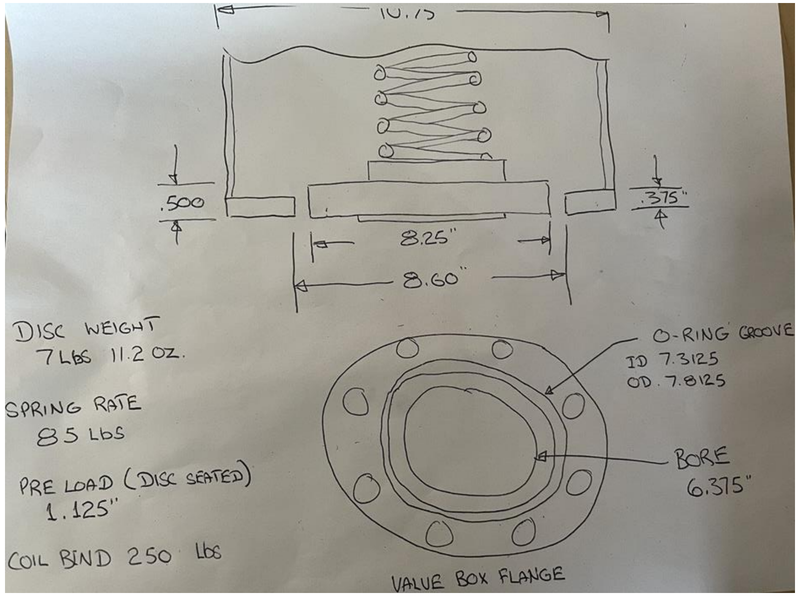
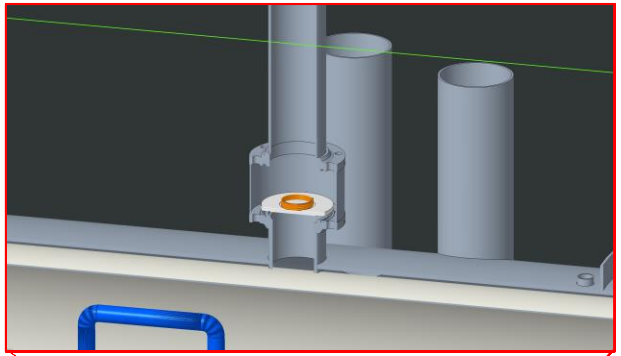
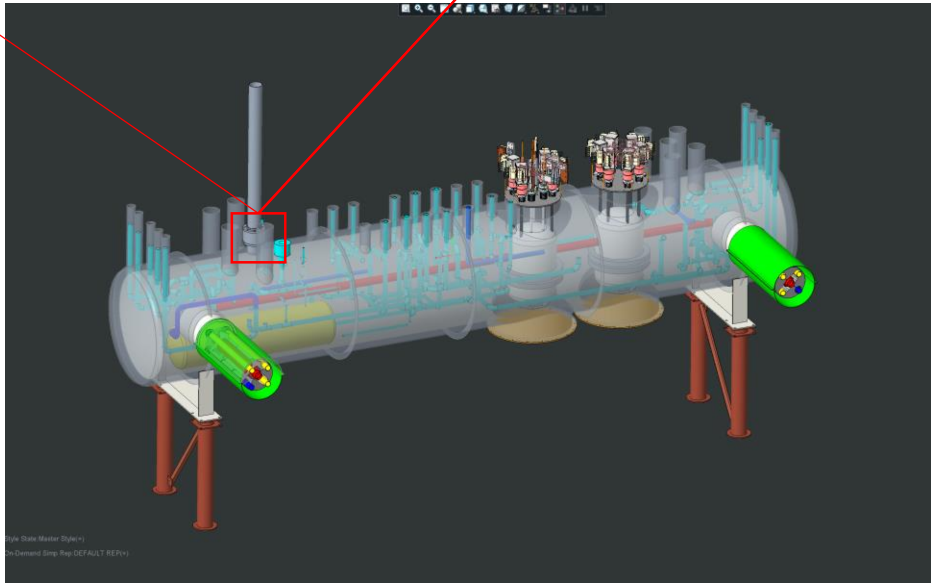
Valve box insulating vacuum relief valve worked as designed

- *Verified lift valve performance by dismantling and measuring properties in the Cryo shop*

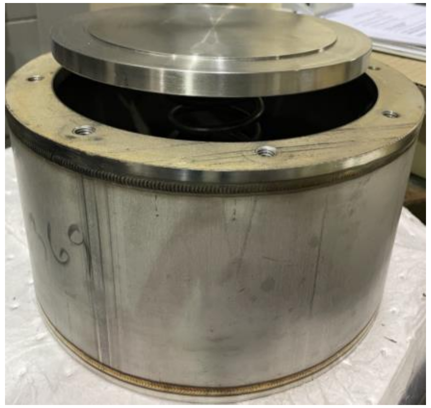
Spring constant [lbs/inch]	85.0
Pre-Load force [lbs]	95.6
Relief set point [PSIG]	1.8
Required Pressure to fully open valve [PSIG]	1.9
Installed relief valve dia [Inch]	6.4
Maximum Pressure buildup in Valve box [PSIG]	3.7
Relief Pressure [PSIA]	18.4





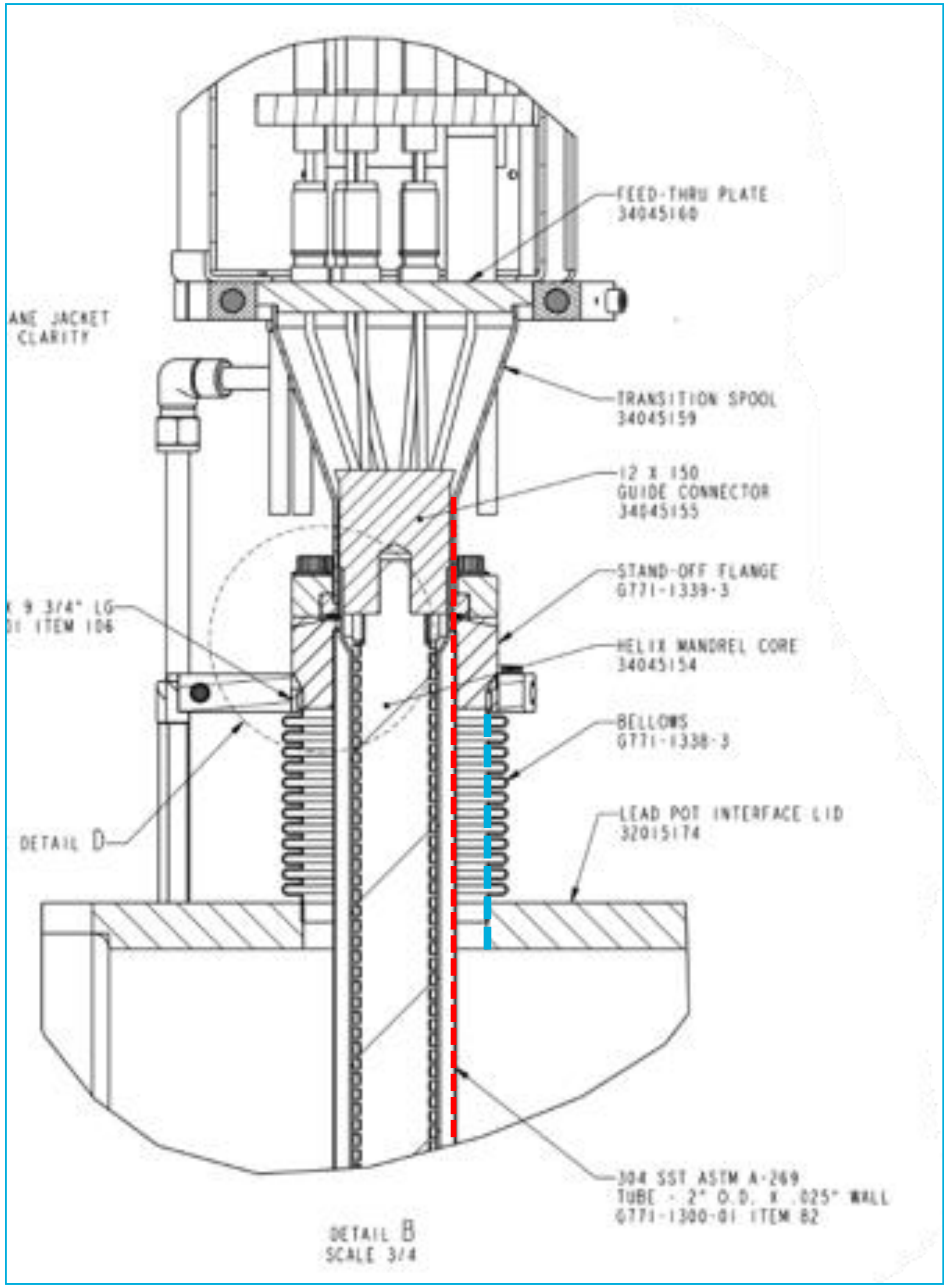


Shown upside down sitting on bench in Cryo shop



1004B Blue Valve Box Repair

Repair Step	Status and notes
Weld in new "TBD" feedthrough tube and bellows, pressure test	**Complete**
Insert, connect, and testing of spare 12X150 current lead	• Start week after Thanksgiving • Electrical team is also working on 4:00 DX splice joints • Finish no later than 12/22
Internal and external electrical work and testing	
Weld lead pots closed	
M-line pressure test from 1004B to 4:00	**Key step.** Need to wait for DX splice cans to be closed. ***Enables start of Cryo scrub.***
Complete MLI and thermal shield installation, other housekeeping	Finish no later than 1/17/24
Re-set relief valve, close manhole covers, pump down	

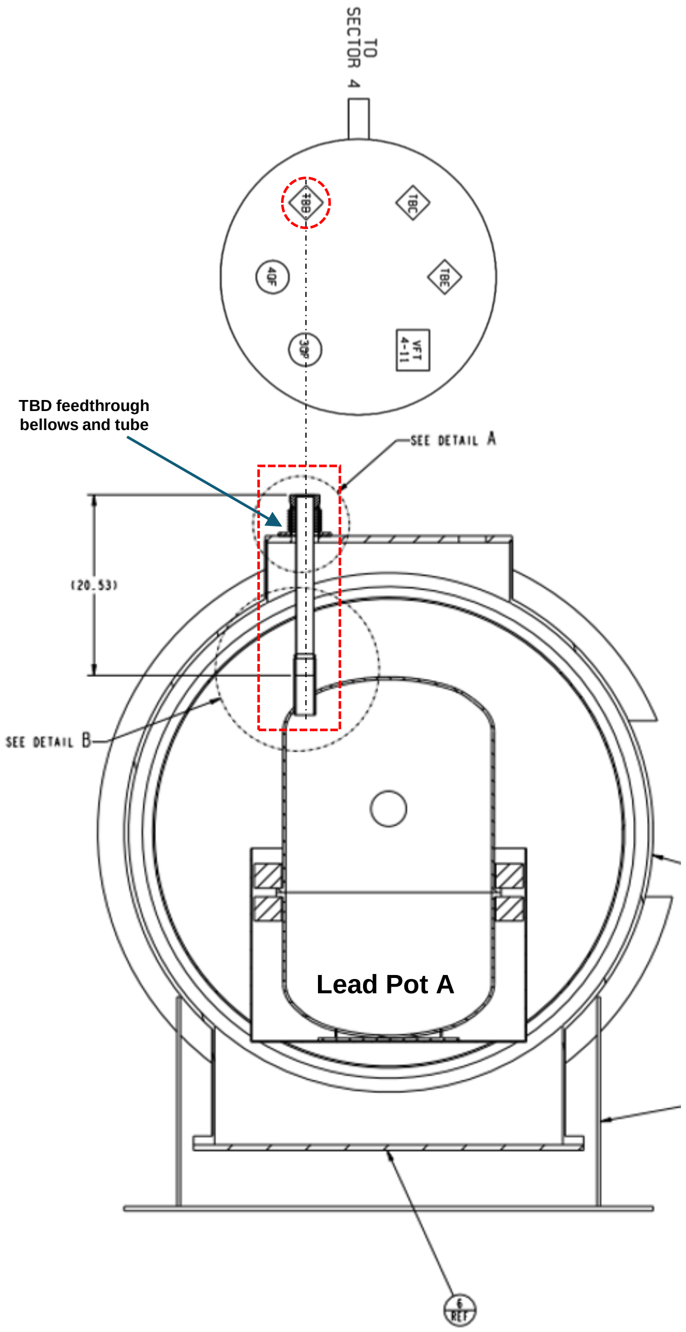


Conclusion: 1004B Blue Valve Box Mechanical Repairs

1. The mechanical work to repair the 1004B blue valve box is well understood and includes:
    1. Designing, fabricating, and installing a new lead-pot "A" feedthrough at the "TBD" position → Complete
    2. Preparing and installing the spare 12X150 current lead and reconnecting all internal cables
    3. *Key-step →* Welding closed the lead pots and pressure-testing the repaired blue M-line pipe run from 1004B to 4:00, including the closed DX magnet M-line splice cans.
    4. Cleaning out and resetting the valve box lift-plate relief valve and relief line
    5. Re-wrapping MLI and re-installing thermal shields and the manhole covers with new o-ring seals
    6. Pumping down the valve box to re-establish insulating vacuum.

2. Work planning for worker ***safety*** is an important part of this repair
    1. Partnered with ES&H to manage hazards, implement LOTO and confined space controls, and ensure the various repair teams have current training and hazard awareness
    2. Working inside the valve box confined space → last entered 20 years ago

3. The Cryo Group mechanical engineering team also performed a bottoms-up ODH analysis of RHIC service buildings
    1. Modeling the mechanics and probabilities of all possible leaks, including the manhole cover frozen o-ring leak and ruptured feedthrough bellows leak cases
    2. There is no change to the valve box manhole cover o-ring design or material because the ODH hazard is covered by the ASE service building credited controls update.
        - *See following talk by Ray Fliller*



Backup material

Other design references

ASME B31.3-2018

Table A-1 Basic Allowable Stresses in Tension for Metals (Cont'd)

Numbers in Parentheses Refer to Notes for Appendix A Tables; Specifications Are ASTM Unless Otherwise Indicated

Nominal Composition	Product Form	Spec. No.	Type/ Grade	UNS No.	Class/ Condition/ Temper	Size, in.	P-No. (5)	Notes	Min. Temp., °F (6)	Specified Min. Strength, ksi: Tensile	Yield	Basic Allowable Stress, S, ksi, at Metal Temperature, °F [Note (1)]: Min. Temp. to 100	200	300	400
Stainless Steel — Pipes and Tubes (3)(4a)															
18Cr–10Ni–Ti	Smls. pipe	A312	TP321	S32100	...	>3/8 thk.	8	(28)	–425	70	25	16.7	*16.7*	*16.7*	*16.7*
18Cr–10Ni–Ti	Smls. pipe	A376	TP321	S32100	...	>3/8 thk.	8	(28)(36)	–425	70	25	16.7	*16.7*	*16.7*	*16.7*
18Cr–8Ni	Tube	A213	TP304L	S30403	...	...	8	(14)(36)	–425	70	25	16.7	*16.7*	*16.7*	**15.8**
18Cr–8Ni	Tube	A269	TP304L	S30403	...	...	8	(14)(36)	–425	70	25	16.7	*16.7*	*16.7*	**15.8**
18Cr–8Ni	Tube	A270	TP304L	S30403	...	...	8	(14)	–425	70	25	16.7	*16.7*	*16.7*	**15.8**
18Cr–8Ni	Pipe	A312	TP304L	S30403	...	...	8	...	–425	70	25	16.7	*16.7*	*16.7*	**15.8**
18Cr–8Ni	Pipe	A358	304L	S30403	...	...	8	(36)	–425	70	25	16.7	*16.7*	*16.7*	**15.8**

The ASME code B31.3 recommends allowable tensile stress levels in pipe materials. The equations used in B31.3 are

$t = P D / (2 (S E + P Y)$ (1)

where

t = thickness of pipe (in)

P = internal pressure in pipe (psi)

D = outside diameter of pipe (in)

S = allowable tensile stress (psi)

E = quality factor for the piping according ASME 31.3

Y = wall thickness coefficient according ASME 31.3 (y = 0.5 for thin pipes and y < 0.5 for thick pipes

or

$t = P (d + 2 c) / (2 (S E - P (1 - Y))$ (2)

where

d = inside diameter of pipe (in)

c = sum of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowances (in) - typical 0.02 in where tolerances are not specified

Eq. (1) can be rearranged to express allowable internal piping pressure as

$p = 2 t S E / (D - 2 t Y)$ (1b)

Eq. (1b) can be modified to compensate for thinner pipes due to the thickness tolerances used by the industry.

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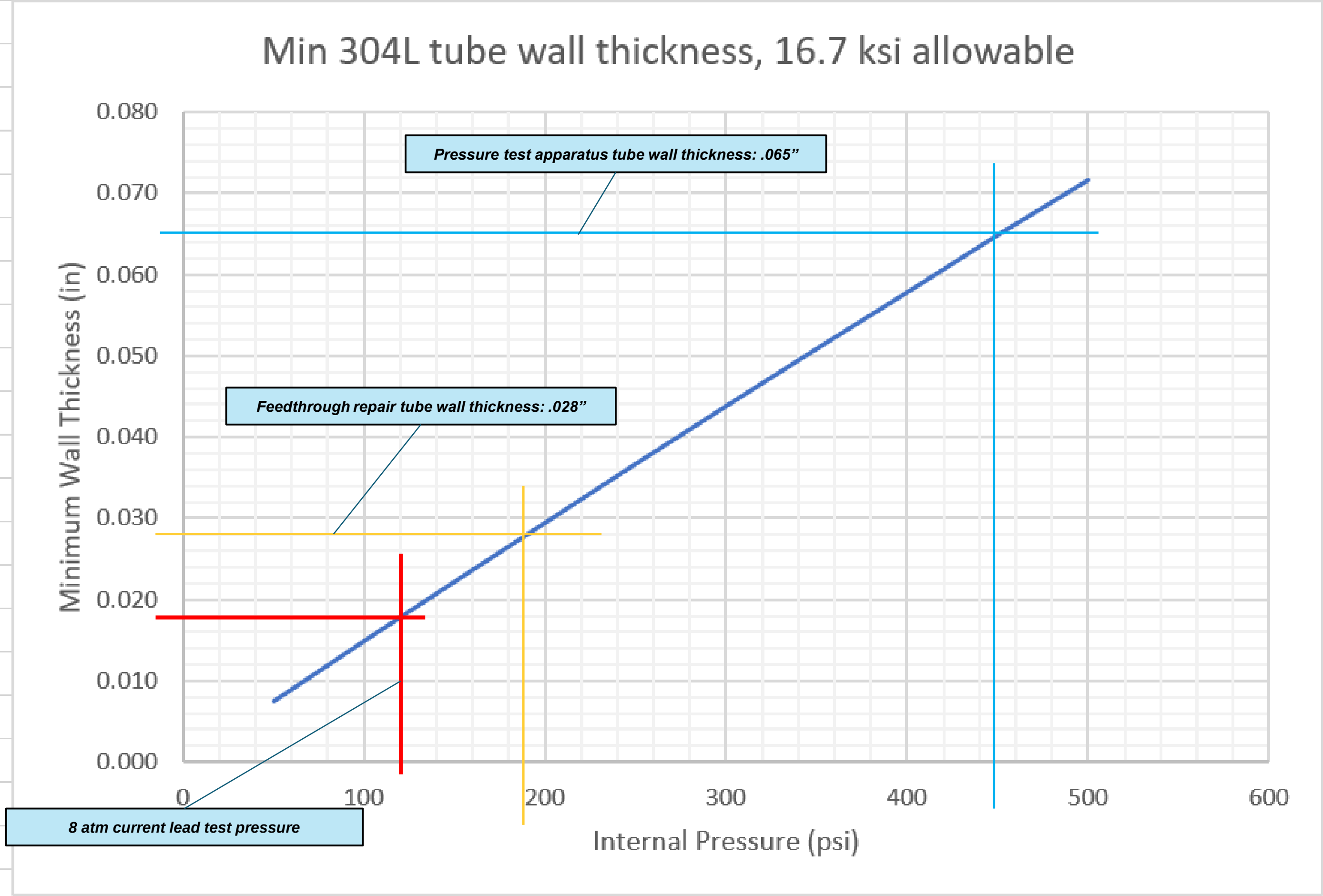
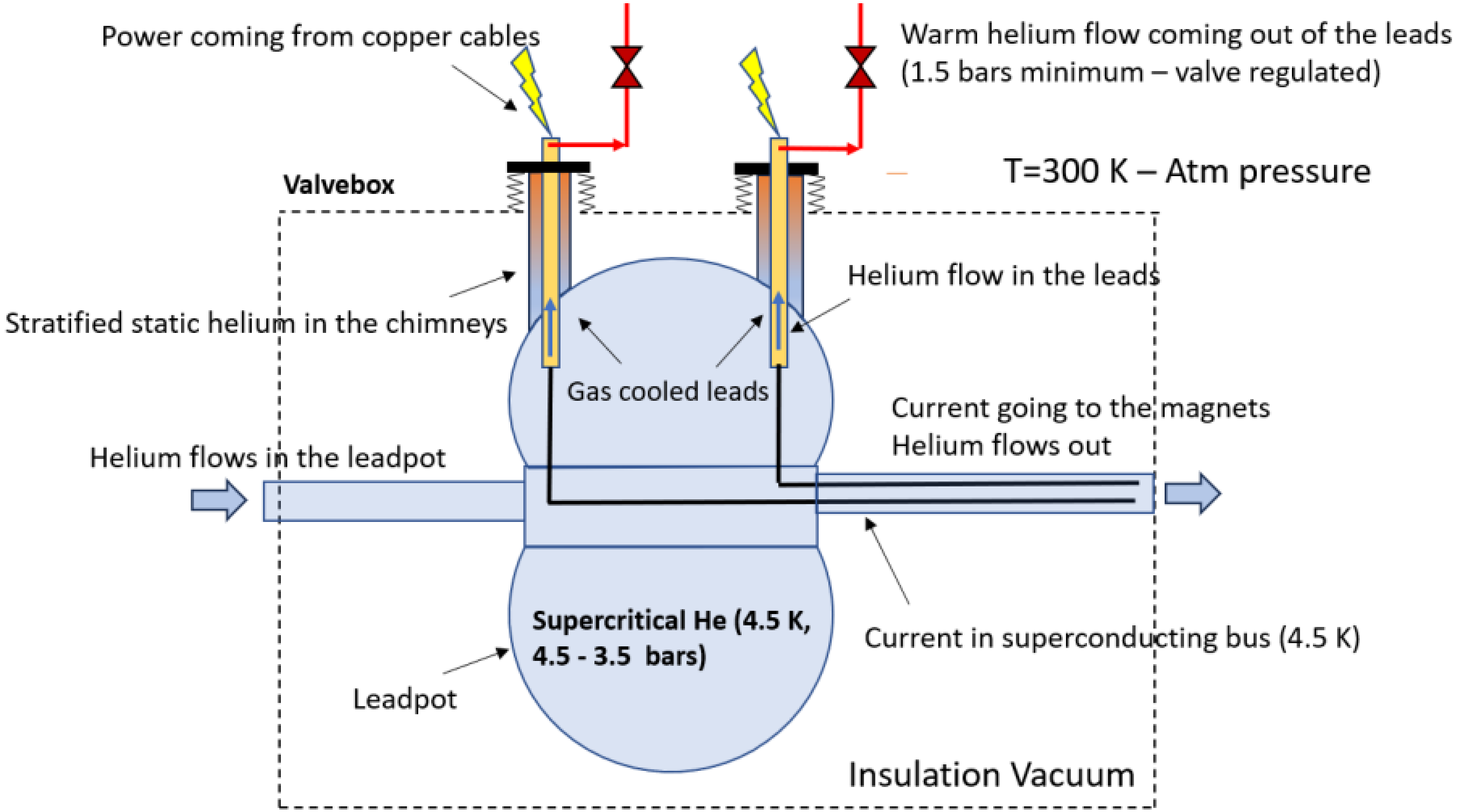
- At the test pressure of 120 psi (8 atm), and using 16.7 ksi allowable, the minimum allowable 304L tube wall thickness is ~.018”
- The test apparatus tube wall is .065”☺
- The test apparatus tube wall is .028”☺

Pipe Diameter (D, in)	2
Allowable Tensile Stress (S, psi)	16,700
Piping Quality Factor (Y)	0.6
Wall Thickness Coefficient (E)	0.4

Pressure (P, psi)	min wall thickness (in)
50	0.007
100	0.015
150	0.022
200	0.029
250	0.037
300	0.044
350	0.051
400	0.058
450	0.065
500	0.072



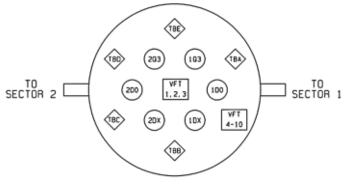
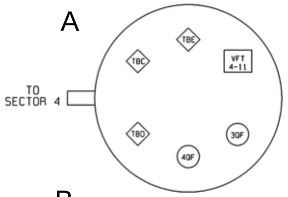
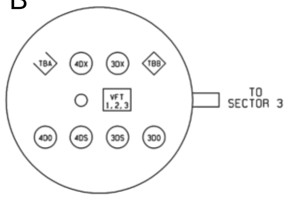
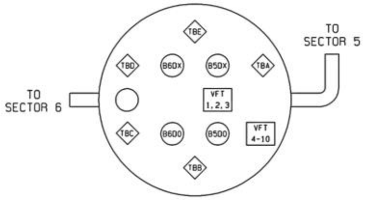
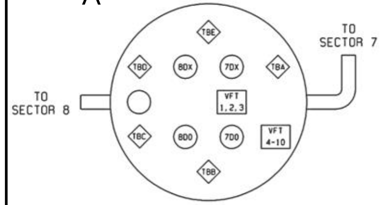
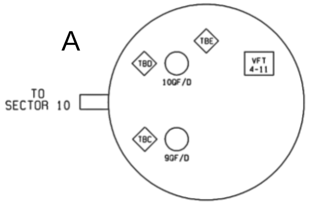
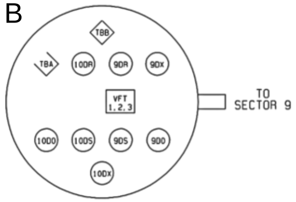
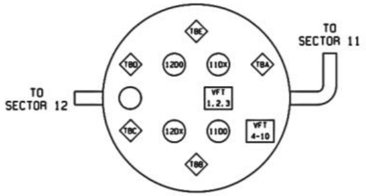
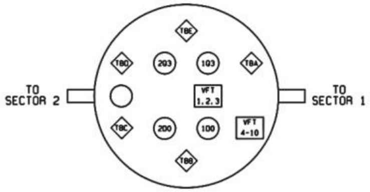
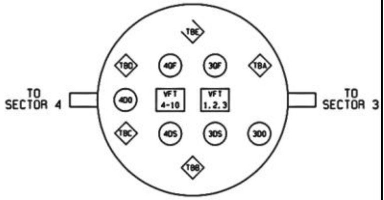
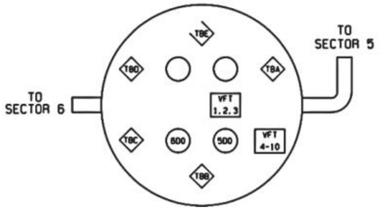
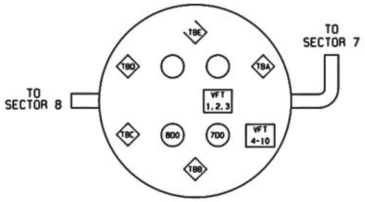
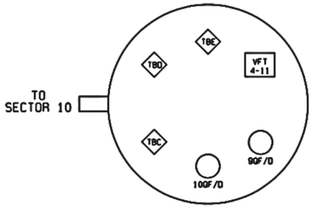
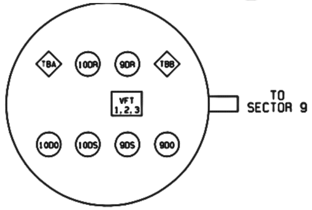
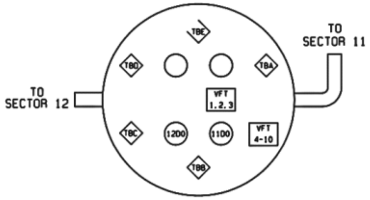
RHIC Valve Box Lead Pots and Gas-Cooled Current Leads



Schematic created by Frederic Micolon

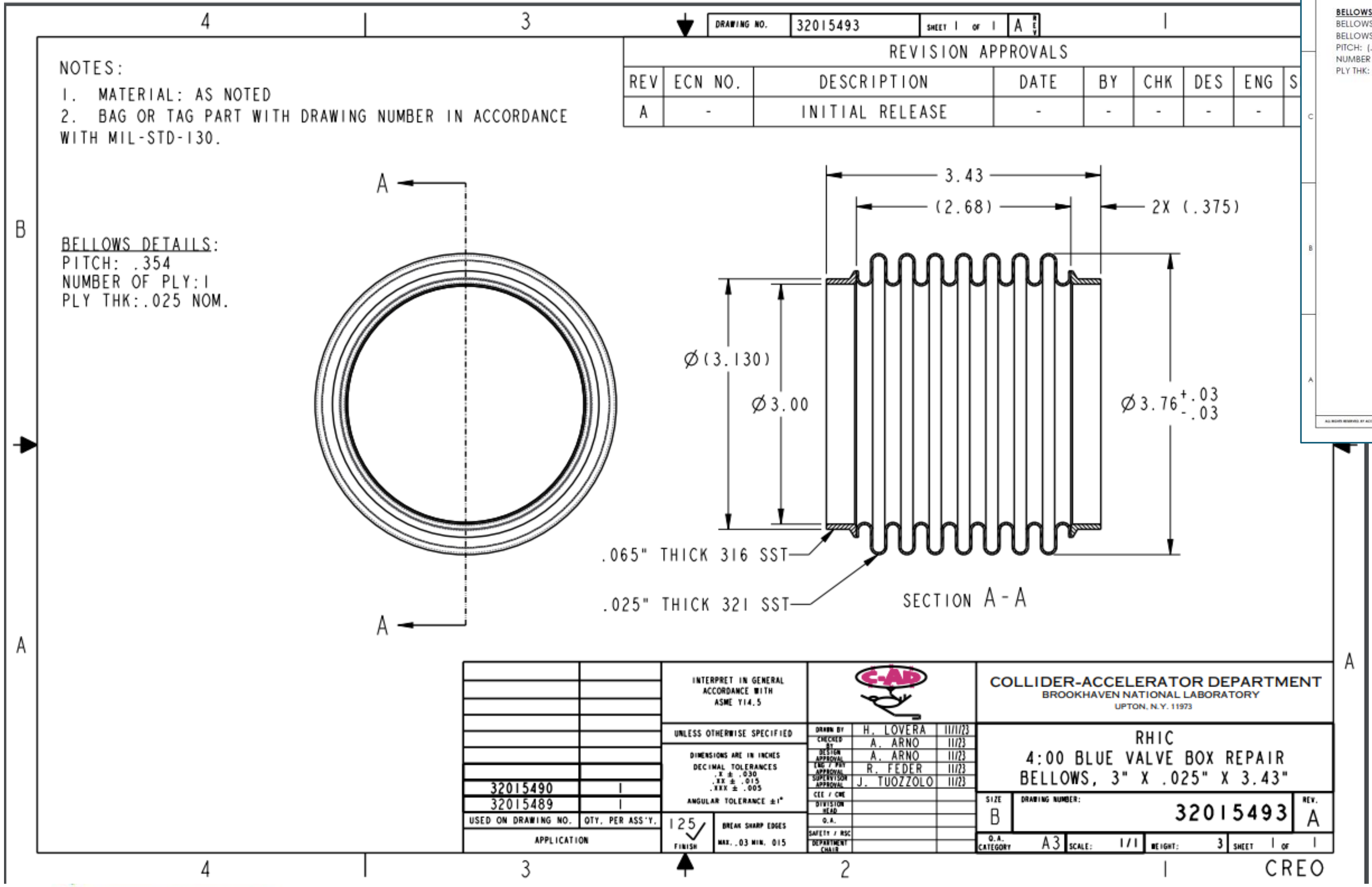
RHIC Valve Box Power Leads Map

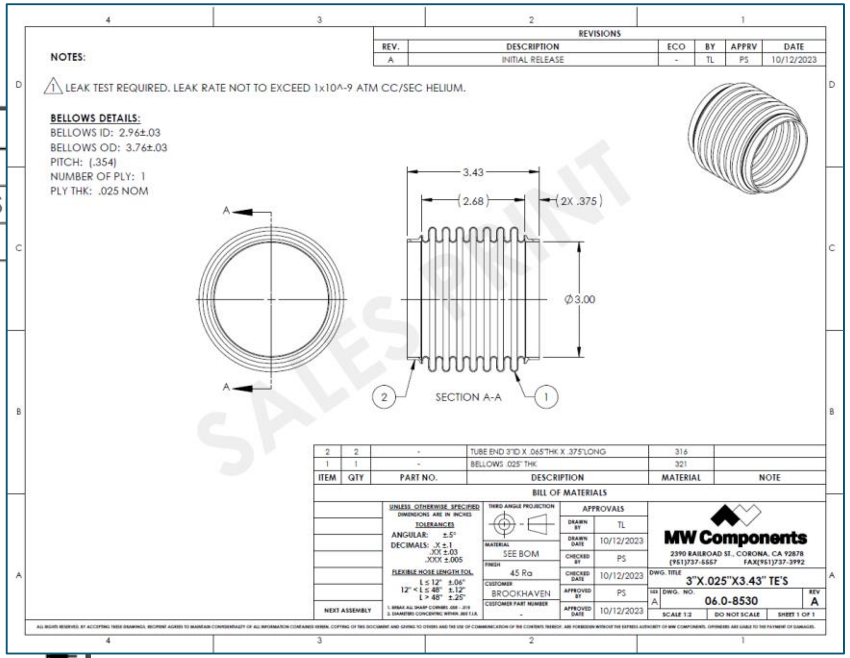
TBX = 12 x 150 amp   12D0 = XXXXXX   XXXX XXXXX = XXXXXX

	2:00	4:00	6:00	8:00	10:00	12:00
B	A 	A  B 	A 	A 	A  B 	
Y					 	

Bellows details: New repair bellows properties

Bellows drawings





Bellows details: New repair bellows properties

Richard Muscolino

After receiving and evaluating the below data from Ameriflex, we are confident both the shorter and the longer version of the replacement bellows currently on order, have enough contraction margin to accommodate our requirement.

The maximum expected contraction of the required bellows movement is ~ 0.090"

See below for details of each new bellows:

1. New Ameriflex Shortened Version – drawing 0608530 attached
2. New Ameriflex Longer(Original Length Version) - drawing 0608531 attached

1. <u>For Part 06.0-8530(the slightly shorter version)</u>
   - Contraction and Expansion limits
     - i. Contraction is rated at 15% of free length 15% of 2.68 is .402"
     - ii. Expansion is rated at 10% of free length 10% of 2.68 is .268"
     - iii. Note these are conservative Theoretical Values
   - Lifetime cycle limits
     - i. 177 cycles at full/maximum contraction and expansion cycle.
   - Spring rate
     - i. 3,892 lbf/in
   - Pitch/Number of Convolutions is different from original sketch sent because after running the numbers a bellows with 8 cons at 2.68 live length and .025" thickness may have premature failure during compression/extension cycles. Hence reducing con count to 7.
2. <u>For part 06.0-8531 (The slightly longer version at 3.8125")</u>
   1. Contraction - .459"
   2. Expansion - .306"
   3. Cycle life – 175 @ maximum contraction/expansion cycle
   4. Spring Rate – 3300 lbf/in

*<u>NOTES:</u>
1. These are Theoretical Values using Ameriflex EJMA calculations.
2. Original CVI Bellows Supplier Drawing – G771-1338
   a. Tom pointed out that the drawing in our system we've been working to doesn't match the actual bellows, we will correct the drawing

To recap our conversation from yesterday, there doesn't seem to be a major concern regarding the specs of the new bellows matching up with the old.
Some back of the napkin calculations, caliper measurements and quick simulations show the properties of the old bellows to be somewhere in this ballpark:

Total free length = ~3.375"
Expansion = 10% Free Length = .337"
Contraction = 15% Free Length = .506"
K = ~2500 lbf/in

Both new bellows (shorter and longer) have very similar amounts of expansion and contraction, but again we don't expect this bellows to need to contract more than 0.100"- both the shorter and longer versions of the new bellows fall well within this range.
The new bellows appear to be a bit stiffer but there isn't any intention for movement once installed.