4 x 6" ROTARY BAYONET LN₂ TEST FILL

J.B. FITZPATRICK

8/02/88

D-ZERO ENGINEERING NOTE #3740.000.EN-171

APPROVED:

G. T. Mallick 8/19/88

INTRODUCTION:

This engineering note describes a test fill of the 4 x 6" rotary bayonet test fixture with LN₂. This test verifies the operation of valves on the fixture, and checks for proper construction/insulation. Further cold testing is imminent (with rotation and moment loading of the bayonet) after proper construction is verified and the test fixture is accepted. While this test fixture is a pressure vessel (4"), it does not require special safety treatment because it is under 6" in diameter. Flow capacity calculations were done to insure that the relief valve chosen would be capable of handling fire/loss of vacuum conditions. The D-Zero Safety Committee Chairman was notified of this testing. (see attached)

TEST FIXTURE DESIGN BACKGROUND:

The desire is to rotate the bayonet under more severe operating conditions than the bayonet will require in its worst case service. The testing is to involve successive days of cold rotation of the bayonet with moment loading. In order for the rotary bayonet to hold enough LN₂ to keep the seal area (see fig 1) cold for a period of around 8 hours (one work shift) the bayonet was made longer. The bayonet was extended as shown in figure 2. A minimum of 4.3 gallons of LN₂ are required to cooldown and fill the structure to a height that will keep the seals cold for about 8 hrs. This is based on a heat leak to the LN₂ of about 27 watts. (see attached calculations).

TEST PROCEDURE:

This test procedure refers to the attached test setup schematic.

PROCEDURE:

1. Secure test fixture against upset.
2. open trycock valve wide
3. open fill valve, wide
4. Slowly open source valve, source pressure approximately = 20 psi
5. Monitor Trycock outlet for; cold gas, colder gas/vapor, finally liquid.
6. Throttle source valve when trycock is "spitting" liquid. When pure liquid, close source.
7. Wait 10 minutes. Close fill valve and disconnect dewar.
8. Close trycock slowly, watch pressure build.
9. Completely close trycock, continue to monitor pressure, assure relief opens at set pressure (20 psig) When stable, can be left alone.

COMMENTS FROM TEST:

The initial setup used 1/4" fill and trycock lines. After one hour of attempting to fill the bayonet test fixture the trycock exhaust was just cold vapor. It was concluded that little or no liquid had collected. The 1/4" lines were changed to 1/2" lines, and the test was rerun. This time the bayonet filled to the desired level in just 7 minutes. After the desired level was reached and the source and trycock valves were closed the pressure in the vessel rose to 20 psig. The relief valve opened and then brought the pressure to equilibrium at about 17 psig. Throughout the fill, no frost or cold spots were to be seen on the outer vacuum vessel indicating that the insulating vacuum and superinsulation were doing their jobs.

ADDITIONAL TESTING:

Additionally, boil-off rate testing was performed on the rotary bayonet to give a better, experimental indication of how long the LN₂ would remain above the o-ring seal area. The attached schematic shows the modifications made to the existing test set-up. The procedure below was followed for the boil-off rate test:

TEST PROCEDURE:

1. Attach rotometer (20-200 scfh) and tee, to 20 psig relief valve as shown.
2. Fill bayonet following previous testing procedure steps 1-7.
3. Cap off the fill line just upstream of the 40 psig relief valve. (see schematic)
4. Open Fill valve wide.
5. Close trycock completely.
6. Monitor and record pressure, and flow rate at regular intervals. (Flow rate is measured by covering the open tee with thumb and reading to the center of the rotometer ball.)

BOIL-OFF TESTING:

Results are depicted in the attached graphs. The boil-off experiment was conducted 3 times. Vessel pressure, and boil-off flow rate were recorded. (Pressure gauge was found to stick during test#2. Pressure readings were disregarded for test#2, and a new pressure gauge installed for test#3)

TEST#1:

The bayonet was filled (20 psig source), then left to sit for about one hour. At that time it was topped off and data was then taken for the next 6 hrs. The bayonet was found to be empty the next morning, 18 hours after the last reading was taken.

TEST#2:

One day passed, then test #1 was repeated. This time the bayonet was filled (35 psig source), left to sit for 25 minutes, then topped off. Readings were then taken for 6 hours, and the Bayonet was topped off just prior to leaving for the day. The next morning, the bayonet was found empty.

TEST#3:

The Bayonet (presumably with residual cold parts) was filled (35 psig source), and topped off 35 minutes later. Readings were then taken for 6 hrs.

RESULTS:

Data from tests #1 and #2 were found to be in close agreement up to the 5 hour mark, at which time the flow rate in test #2 dropped off considerably. Tests #1 and #2 both show time constants (time to reach 63.3 % of steady state value) of about 2 hours. A steady state boil-off rate of 15 SCFH was common to both tests and in close agreement to a calculated rate of 13.7 SCFH.

Data from test #3 indicated a time constant of about one and one-half hours showing that there probably were some residual cold parts in the bayonet fixture. The steady state flow rate was only about 10 SCFH.

*It should be noted that the Rotometer used had a 20-200 SCFH range and therefore the steady state readings were offscale. Below 20 SCFH, a reasonable extrapolation is all that this data represents.

The conclusion of this boil-off testing is that the calculated steady state boil-off rate is in strong agreement with the measured rate, but the transient boil-off period is too large to sustain LN₂ above the seal area for the proposed 8 hours of testing (sustained only 4 to 5 hours). The area under the flow rate vs. time graph represents the amount of GN₂ boil-off. Roughly twice the amount of GN₂ boils-off in 8 hours than is required to keep the o-ring seal area under liquid level (100 SCF required, 200 SCF boil-off). One of two things can be done in order to correct this situation. The bayonet test fixture could be modified by adding more volume above the seal area, or the bayonet could be refilled at the 4 hour mark during testing.

CONCLUSION:

This test fixture is currently being enlarged to hold enough LN₂ for an 8 hour test and take up the necessary thermal contractions. Initial design considerations had insufficient means to support the thermal contraction of the inner pipe relative to the outer pipe. The modified test fixture will remain under 6" in diameter so it does not require special safety treatment. All modifications and future testing results will be appended to this report.

6/30/88 TP

CRYOLAB 4x6 ROT. BAYONET (FEMALE)

6.37

5.879

RET. RING
5.982 I.D.

5160-625

B
32

17.85"
O.A.H.T.

TEFLON BRG. RING.

5.450
5.850

TEFLON BRG. RING

BRASS LOCK RING

6/30/88

TP

BRASS CLAMP RING.

4x6 ROT. BAYONET (CRHOLAE)

O-RING. #2-255

.139" $\pm .004$ I.D. 5.609 $\pm .035$

EXISTING DIM'S.

SQUEEZE $5.879 - 5.611 = .268 / 2 = .134$

$$\frac{.143_{\text{mx}}}{.135_{\text{mn}}} - \frac{.134}{.134} = \frac{.009}{.001} \begin{matrix} (6\%) \\ (.7\%) \end{matrix}$$

(RECOMMENDED)

AG-5

.003 TIR

**extended
rotary bayonet
figure 2**

JBF 8/88
NTS

4 X 6" ROTARY BAYONET TEST FIXTURE
LN2 FILL SETUP
SCHEMATIC

4 X 6" ROTARY BAYONET TEST FIXTURE

JBF 7/88

BOIL-OFF TEST SCHEMATIC

Data from "BOIL-OFF DATA #1"

Data from "BOIL-OFF DATA"

Data from "BOIL-OFF DATA #2"

NO DATA AVAILABLE

Data from "BOIL-OFF DATA #3"

Data from "BOIL-OFF DATA #3"

	TIME (MIN)	PRESS (PSIG)	FLOW (SCFH)	TIME (HRS.)
1	0	13	0	0.000
2	3	15.5	40	0.050
3	8	16.5	65	0.133
4	13	16.75	70	0.217
5	33	16.25	60	0.550
6	38	16.25	60	0.633
7	58	16.0	55	0.967
8	60	16.0	55	1.000
9	63	16.0	55	1.050
10	78	15.9	50	1.300
11	83	15.9	50	1.383
12	98	15.5	45	1.633
13	133	15.0	30	2.217
14	163	14.75	20	2.717
15	178	14.5	20	2.967
16	198	14.25	15	3.300
17	233	14.0	15	3.883
18	283	14.0	15	4.717
19	303	13.9	15	5.050
20	360	13.9	15	6.000

	TIME (MIN)	PRESS (PSIG)	FLOW (SCFH)	TIME (HRS.)
1	0	NO DATA	0	0.000
2	7		0	0.117
3	10		45	0.167
4	25		70	0.417
5	40		65	0.667
6	70		50	1.167
7	95		45	1.583
8	110		35	1.833
9	160		20	2.667
10	175		15	2.917
11	220		15	3.667
12	280		15	4.667
13	310		15	5.167
14	380		1	6.333

	TIME (MIN)	PRESS (PSIG)	FLOW (SCFH)	TIME (HRS.)
1	0	16.0	55	0.000
2	5	16.5	70	0.083
3	30	17.0	90	0.500
4	60	16.75	80	1.000
5	90	16.25	60	1.500
6	120	15.0	25	2.000
7	150	14.9	20	2.500
8	180	14.5	15	3.000
9	225	14.25	10	3.750
10	255	14.25	10	4.250
11	300	14.25	10	5.000
12	345	13.9	1	5.750

From: FNAL::MULHOLLAND 28-JUL-1988 13:02
To: FITZPA
Subj: Information

From: FNAL::MULHOLLAND 28-JUL-1988 11:57
To: QCRYOPANEL, MULHOLLAND
Subj: Rotary Bayonet test

This note is inform you of our intent to commission a 4" diameter pressure vessel, the 4X6" bayonet in the test, today. This vessel needs no special safety treatment because it is less than 6" in diameter. I will be forwarding a note indicating the pressure rating and relief sizing considerations as a matter of information. Refer your questions to Brian Fitzpatrick (Fitzpa) or me.

From: FNAL::FITZPA 28-JUL-1988 11:52
To: MULHOLLAND,FITZPA
Subj: RELIEF VALVE FOR 4" CLOSED PIPE

I HAVE DONE CALCULATIONS FOR REQUIRED FLOW CAPACITIES UNDER LOSS OF VACUUM, AND FIRE CONDITIONS AND FIND THAT THE NUPRO RELIEF VALVE SERIES 8C WILL HANDLE THE WORST CASE FLOW OF 10 SCFM-AIR WHEN SET AT 15 P.S.I.G. (HANDLES BETTER THAN 20 SCFM-AIR). I FIND NO PROBLEM WITH USING THIS RELIEF VALVE ON THE 4" ENCLOSED ROTARY BAYONET TEST FIXTURE.

From: FNAL::MULHOLLAND 4-AUG-1988 07:41
To: FITZPA
Subj: Information

From: FNAL::FAST 3-AUG-1988 13:01
To: FNAL::MULHOLLAND,FAST
Subj: RE: Rotary Bayonet test

I concur that a vessel with a diameter of 4" does not fall under the provisions of the ASME BPV Code and the Fermilab Safety Manual and therefore a "14.1 Engineering Note" is not required. The Panel would appreciate learning more about this rotary bayonet test and results at some future monthly meeting.

"C" & "CA" SERIES CHECK & ADJUSTABLE IN-LINE RELIEF VALVES

FLOW CAPACITY

Cracking Pressure (PSI)	Flow Rate (GPM)	Flow Rate (LPM)
10	2.21	0.51
50	6.12	1.13
100	10.85	1.60

Cracking Pressure (PSI)	Flow Rate (GPM)	Flow Rate (LPM)
10	6.50	1.49
50	17.98	3.32
100	31.87	4.70

Cracking Pressure (PSI)	Flow Rate (GPM)	Flow Rate (LPM)
10	20.33	4.65
50	56.23	10.39
100	99.68	14.70

Cracking Pressure (PSI)	Flow Rate (GPM)	Flow Rate (LPM)
10	22.96	5.25
50	63.49	11.74
100	112.56	16.60

Cracking Pressure (PSI)	Flow Rate (GPM)	Flow Rate (LPM)
10	5.14	1.17
50	14.01	2.62
100	24.84	3.70

NOTE: Higher cracking pressures may reduce the flow rate.

MATERIALS

Body, Poppet, Nuts & Ferrules — Brass, 316 stainless steel, Monel, and aluminum.

Spring — Type 302 stainless steel in all valves, except Monel valves use Monel springs.

Gasket ("CA" Series only) — TFE coated 316 stainless steel; Monel valves use TFE coated Monel.

O-Ring — Buna "N" is standard in brass and aluminum valves. Viton is standard in stainless steel and Monel valves. Many different types of elastomer O-Rings are stocked by NUPRO Company for specialized applications. Due to the hardness of TFE, O-Rings of this material will not seal leak-tight except with very high back pressure. TFE O-Rings are useful on cycling pump applications where gas tight sealing is not required and pressure surges are common.

Adjusting Screw, Lock Screw ("CA" Series Only) — brass, aluminum, and 316 stainless steel valves use 316 stainless steel. Monel valves use Monel.

TABLE OF DIMENSIONS

Model	Cracking Pressure (PSI)	Flow Rate (GPM)	Body Material	Port Size	Port Type	Port Size	Port Type	Port Size	Port Type
-2C-	.094	2.4	% SWAGELOK	% SWAGELOK	2 $\frac{1}{32}$	$\frac{3}{32}$	$\frac{1}{8}$	%	
-2C2-	.125	3.2	% Male NPT	% Male NPT	1 $\frac{1}{32}$	$\frac{3}{32}$	—	%	
-2C4-	.187	4.7	% Female NPT	% Female NPT	2 $\frac{1}{8}$	—	—	%	
-4C-	.187	4.7	% SWAGELOK	% SWAGELOK	2 $\frac{1}{32}$	$\frac{3}{32}$	$\frac{1}{8}$	%	
-4C-VCR-	.187	4.7	% VCR	% VCR	2 $\frac{1}{32}$	$\frac{3}{32}$	—	%	
-4C1-	.187	4.7	% Male NPT	% SWAGELOK	2 $\frac{1}{4}$	$\frac{3}{32}$	$\frac{1}{8}$	%	
-4C2-	.187	4.7	% Male NPT	% Male NPT	2 $\frac{1}{32}$	$\frac{3}{32}$	—	%	
-4C4-	.187	4.7	% Female NPT	% Female NPT	2 $\frac{1}{32}$	—	—	%	
-4CA-	.156	4.0	% SWAGELOK	% SWAGELOK	3 $\frac{1}{32}$	1 $\frac{1}{16}$	$\frac{1}{8}$	%	
-4CA1-	.156	4.0	% Male NPT	% SWAGELOK	3 $\frac{1}{16}$	1 $\frac{1}{16}$	$\frac{1}{8}$	%	
-6C-	.281	7.1	% SWAGELOK	% SWAGELOK	3 $\frac{1}{32}$	1 $\frac{1}{32}$	$\frac{1}{8}$	%	
-6C2-	.359	9.1	% Male NPT	% Male NPT	2 $\frac{1}{2}$	1 $\frac{1}{32}$	—	%	
-6C4-	.359	9.1	% Female NPT	% Female NPT	3	—	—	%	
-8C-	.359	9.1	% SWAGELOK	% SWAGELOK	3 $\frac{1}{16}$	1 $\frac{1}{16}$	$\frac{1}{8}$	%	
-8C2-	.359	9.1	% Male NPT	% Male NPT	3 $\frac{1}{32}$	1 $\frac{1}{32}$	—	%	
-8C4-	.359	9.1	% Female NPT	% Female NPT	3 $\frac{1}{16}$	—	—	1 $\frac{1}{8}$	
-10C-	.359	9.1	% SWAGELOK	% SWAGELOK	3 $\frac{1}{16}$	1 $\frac{1}{16}$	1	1 $\frac{1}{8}$	
-6C-MM	.187	4.7	6mm SWAGELOK	6mm SWAGELOK	2 $\frac{1}{32}$	$\frac{3}{32}$	$\frac{1}{8}$	%	
-10C-MM	.281	7.1	10mm SWAGELOK	10mm SWAGELOK	3 $\frac{1}{32}$	1 $\frac{1}{32}$	$\frac{1}{8}$	%	
-12C-MM	.359	9.1	12mm SWAGELOK	12mm SWAGELOK	3 $\frac{1}{16}$	1 $\frac{1}{16}$	$\frac{1}{8}$	%	

*For a complete ordering number:

- Add B for brass, SS for 316 stainless steel, A for aluminum and M for Monel as a prefix to the catalog number. Example: SS-2C-
- For "C" Series valves, add 1/3, 1, 10, or 25 as a suffix to the catalog number for the desired cracking pressure. Special springs to 100 PSI cracking pressures are available. Example: B-4C-1
- For "CA" Series valves, add 3 for 3 to 50 PSI cracking pressures, 50 for 50 to 150 PSI, 150 for 150 to 350 PSI, or 350 for 350 to 600 PSI as a suffix to the catalog number for the desired cracking range. Example: SS-4CA-3

*Dimensions shown with SWAGELOK nuts finger-tight, when applicable.

NUPRO COMPANY • 4800 E. 345th Street • Willoughby, Ohio 44094

INTRODUCTION

SCOPE

U-1 SCOPE¹

(a) For the scope of this Division, pressure vessels are containers for the containment of pressure, either internal or external. This pressure may be obtained from an external source, or by the application of heat from a direct or indirect source, or any combination thereof.

(b) This Division is divided into three Subsections. Subsection A consists of Part UG, covering the general requirements applicable to all pressure vessels. Subsection B covers the specific requirements that are applicable to the various methods used in the fabrication of pressure vessels. It consists of Parts UW, UF, and UB, dealing with welded, forged, and brazed methods, respectively. Subsection C covers specific requirements applicable to the several classes of materials used in pressure vessel construction. It consists of Parts UCS, UNF, UHA, UCI, UCL, UCD, and UHT, dealing with carbon and low-alloy steels, nonferrous metals, high-alloy steels, cast iron, clad and lined material, cast ductile iron, and ferritic steels with properties enhanced by heat treatment, respectively.

(c) The following classes of vessels are not considered to be within the scope of this Division:

- (1) those within the scope of other Sections
- (2) fired process tubular heaters
- (3) pressure containers which are integral parts or components of rotating or reciprocating mechanical devices, such as pumps, compressors, turbines, generators, engines, and hydraulic or pneumatic cylinders where the primary design considerations and/or stresses are derived from the functional requirements of the device

(4) except as covered in U-1(f), structures whose

primary function is the transport of fluids from one location to another within a system of which it is an integral part, that is, piping systems

(5) piping components, such as pipe, flanges, bolting, gaskets, valves, expansion joints, fittings, and the pressure-containing parts of other components, such as strainers and devices which serve such purposes as mixing, separating, snubbing, distributing, and metering or controlling flow, providing that pressure-containing parts of such components are generally recognized as piping components or accessories

(6) vessels with a nominal water-containing capacity of 120 gal (454 l) or less for containing water² under pressure, including those containing air, the compression of which serves only a cushion

(7) a hot water supply storage tank heated by steam or any other indirect means when none of the following limitations is exceeded:

(a) a heat input of 200,000 Btu/hr (58.6 kW)

(b) a water temperature of 210°F (99°C)

(c) a nominal water-containing capacity of 120 gal (454 l)

(8) vessels having an internal or external operating pressure [see 3-1(f)] not exceeding 15 psi (103 kPa) with no limitation on size [see UG-28(e)]

(9) vessels having an inside diameter, width, height, or cross section diagonal not exceeding 6 in. (152 mm), with no limitation on length of vessel or pressure

(d) The rules of this Division have been formulated on the basis of design principles and construction practices applicable to vessels designed for pressures not exceeding 3,000 psi (20 670 kPa). For pressures above 3,000 psi (20 670 kPa), deviations from and additions to these rules usually are necessary to meet the requirements of design principles and construction practices for these higher pressures. Only in the event that after having applied these additional design principles and construction practices the vessel still

¹In those applications where there are laws or regulations issued by Municipal, State, Provincial or Federal Authorities covering pressure vessels, these laws or regulations should be reviewed to determine size or service limitations of the coverage which may be different or more restrictive than those given in this paragraph.

²The water may contain additives provided the flash point of the aqueous solution at atmospheric pressure is 185°F (85°C) or higher.

Fire Conditions (Cont)

$$Q_{N_2} = (10.2) \frac{(.0367)}{(.15475)} (4.1) @ 1200^\circ F N_2$$

$$= 9.92 \text{ SCFM-} N_2 \times \frac{\sqrt{29}}{\sqrt{28}}$$

$$= \boxed{10.1 \text{ SCFM-Air}}$$

Conclusion: MAX Flow RATE is under Fire Conditions. $\approx 10 \text{ SCFM-air}$

NuPRO 8C ($\frac{1}{2}$ Swage-Lock) Relief Valve
Handles A Flow of 22.96 SCFM-air
at 10 psig, & its MAX flow increases
w/ pressure drop.

CALCULATION of flow RATE for LOSS of VACUUM w/ INSULATION

ASSUME VAC SPACE at 1 atm.

USE $K_{air} > K_{N_2}$ @ $80^\circ F$

$$\text{Heat TRANSFER} = U * A * \Delta T$$

$$= \frac{(.01516)}{(.15475)} \left(\pi \frac{4.5}{12} \frac{57}{12} \right) (80 - (-303))$$

$$= 209.9 \approx \underline{\underline{210 \frac{BTU}{HR}}}$$

NOW GET flow RATE:

$$Q_{N_2} = \left(210 \frac{BTU}{HR} \right) * \frac{1g}{47.6cal} * \frac{252cal}{BTU} * \frac{1L}{1.25g}$$

$$* \frac{1hr}{60min} * \frac{0.1337 ft^3}{3.785 L}$$

$$= 0.5236 SCFM-N_2 * \frac{\sqrt{29}}{\sqrt{28}}$$

$$= \boxed{0.533 SCFM-Air}$$

FIRE CONDITIONS

$$Q_{AIR} = G_{N_2} \frac{K}{\Delta R} A^{0.82}$$

@ $1200^\circ F$ AIR

$$= (10.2) \frac{(.0351) \frac{BTU}{hr.ft.F}}{(.15475)} \left(\pi \left(\frac{4.5}{12} \right) \left(\frac{57}{12} \right) \right)^{0.82}$$

$$\boxed{Q_{AIR} = 9.5 SCFM-AIR}$$

$$\uparrow A^{0.82} = 4.1$$

calculations

CALCULATE HEAT LEAK TO ROTARY BAYONET TEST
(4x6") Fixture

① $Q_{\text{conv}} \equiv$ Negligible Due to Insulation & Vacuum.

② $Q_{\text{cond}} \equiv \frac{\mu \Delta T A}{\Delta X}$

$\mu = .72 \frac{\text{mW}}{\text{cm-K}}$ for LAMINE Insulation.

$$\equiv \frac{\left(.7 \frac{\text{mW}}{\text{cm-K}}\right) \times \left(\frac{1 \text{ W}}{10^6 \text{ mW}}\right) (300-77) \left(142 \left(\frac{\pi}{4} (6.357)^2\right)\right)}{1'' (2.54)}$$

$$= \boxed{1.78 \text{ W}}$$

③ $Q_{\text{COND}} = \frac{K \Delta T A}{\Delta X}$ $K \Delta T_{SS} = 27.3 \text{ W/cm}$

$$A = \frac{\pi}{4} \left((4.5(2.54))^2 - (4.26(2.54))^2 \right)$$

$$= 10.65 \text{ cm}^2$$

LEAK 1° $\Delta X \approx 20'' (2.54) = 50.8 \text{ cm}$

Male
piece

$$Q = \frac{(27.3)(10.65)}{50.8} = \boxed{5.72 \text{ W}}$$

Leak 2° $\Delta X \approx 14.5'' (2.54) = 36.83 \text{ cm}$

Female
piece.

$$Q = \frac{(27.3)(10.65)}{36.83} = \boxed{7.89 \text{ W}}$$

Leak 3° $\Delta X = 10'' (2.54) = 25.4 \text{ cm}$

Top
plate

$$Q = \frac{(27.3)(10.65)}{25.4} = \boxed{11.45 \text{ W}}$$

②

$$\begin{aligned} Q_{TOT} &= \cancel{Q_{conv}}^0 + Q_{rad} + Q_{cond} \\ &= (1.78) + (5.72 + 7.89 + 11.45) \\ &= \boxed{26.83 \text{ W}} \end{aligned}$$

Bayonet
COOLdown of 4x6" TEST Fixture

$$\Delta H_{ss} \approx \Delta H_{Fe} = (81.1 - 3.43) = 77.67 \frac{J}{g}$$

$$A_{cs} = \frac{\pi}{4} ((4.5(2.54))^2 - (4.260(2.54))^2) \\ = 10.65 \text{ cm}^2$$

$$l = 56''(2.54) = 142.0 \text{ cm}$$

$$Wt. = \rho_{ss} \times (10.65 \text{ cm}^2)(142.0 \text{ cm}) = \rho A_{cs} l \\ = \boxed{12,098 \text{ g}}$$

$$Q_{cd} = (77.67)(12,098) = \boxed{9.4 \times 10^5 \text{ J}}$$

LN₂ Heat of Vaporization $\approx 200 \text{ J/g}$

$$\frac{9.4 \times 10^5 \text{ J}}{200 \text{ J/g}} = \boxed{4700 \text{ g LN}_2} \text{ need to} \\ \text{Be Vaporized.}$$

(Minimum Requirement)

$$4700 \text{ g LN}_2 \div 0.808 \text{ g/mL} = 5816 \text{ mL} \\ \approx 5.81 \text{ L}$$

$$\approx 5.81 \text{ L} \times \frac{1 \text{ gal}}{3.785 \text{ L}}$$

$$= \boxed{1.53 \text{ GAL LN}_2}$$

ONCE COOLDOWN, LN₂ TO Fill?

$$V = Al = \frac{\pi}{4} (4.26 (2.54))^2 \left(\frac{117}{144} \right)$$

$$= \cancel{13,759 \text{ cm}^3}$$

$$= 10,759 \text{ cm}^3 = 10.75 \text{ L} \times \frac{1 \text{ gal}}{3.785 \text{ L}}$$

$$= \boxed{2.77 \text{ GAL LN}_2}$$

TOTAL LN₂ NEEDED TO COOLDOWN & FILL

$$\begin{array}{ccc} \text{cool down} & + & \text{Fill} \\ 1.53 \text{ GAL} & + & 2.77 \text{ GAL} = \boxed{4.3 \text{ GAL MINIMUM}} \end{array}$$

ONCE Filled, How long will it LAST

$$\text{Have; } \underline{2.77 \text{ Gal}} = 10.48 \text{ L} \Rightarrow \underline{8468 \text{ g LN}_2}$$

TOTAL

HEAT LEAK AT $t=0$ is 26.83 W

LEAK 3 is Reduced with time As Boiloff occurs.

Worst case would be if LEAK 3 Remained
THE whole time. (TRYing to MAXimize TIME)

SO To Keep LN₂ above seals:

NEED g LN₂ above seals.

$$\text{A Bout } 20''(2.54) = 50.8 \text{ cm} \times \frac{\pi}{4} (4.26(2.54))^2$$

$$= 4671 \text{ cm}^3 = 4.67 \text{ L}$$

$$\Rightarrow 3774 \text{ g LN}_2 \text{ above SEALS to START}$$

REAL Question is How long to
Boil THIS off?

$$\text{THIS Requires } 200 \text{ J/g} (3774 \text{ g}) = 7.5 \times 10^5 \text{ J}$$

W/ HEAT LEAK AT $26.83 \frac{J}{s}$;

$$\frac{7.5 \times 10^5 J}{26.83 \frac{J}{s}} = 28132.6 \text{ Sec}$$

$$= 469 \text{ min.}$$

$$= \boxed{7.8 \text{ hr.}}$$

AT LEAST!

WHAT IS Boil off RATE?

4.7 L LN_2 get Boiled off in 7.8 hr.

$$4.7 \text{ L } LN_2 \times \frac{22.8 \text{ scf } GN_2}{1 \text{ L } LN_2} = 107.16 \text{ scf}$$

$$\frac{107.16 \text{ scf}}{7.8 \text{ hr}} = \boxed{13.7 \text{ scfh}}$$