# E706 CRYOSYSTEM DESIGN NOTE

# E706EN013

**TITLE:** Pressure Vessel Engineering Note (14.1)

$LN_2$ Storage Dewar; RD2045-NB8602

**AUTHOR:** Danny D. Burke, ME, RD/Cryogenics Department

**DATE:** October 22, 1986

**REVIEWED BY:**

| | | | |
|---|---|---|---|
| | | Kelley Dixon | 27 Oct 86 |
| Name | Date | Project Manager | Date |

PRESSURE VESSEL ENGINEERING NOTE
PER MANDATORY STANDARD SD37
(CHAPTER 14.1, LAB SAFETY MANUAL)

Prepared by: Dan Burke Ext. 3355
Preparation date: 14 Nov. 1985

5.1 Description and Identification

Fill in the label information below:

This vessel conforms to engineering standard SD37

Vessel Title LN2 STORAGE DEWAR

Vessel Number RD 2045; NB 8602 ← Obtain from Division/Section Safety Officer

Vessel Drawing Number NA

Maximum Allowable Working Pressure (MAWP) 78/EV PSIG

Working Temperature Range -320 °F - 100 °F

Contents Liquid Nitrogen

Designer/Manufacturer MVE Cryogenics

Test Pressure (if tested at Fermi) Acceptance Date: NA

PSI, Hydraulic Pneumatic

Accepted as conforming to standard by K. C. Stanfield ← Actual signature required in this space

of Division/Section Research Div.

NOTE: Any subsequent changes in contents, pressures, temperatures, valving, etc., which affect the safety of this vessel shall require another review and test.

Reviewed by: [signature] Date: Oct. 20. 86

Director's signature (or designee) if the vessel is for manned areas but doesn't conform to the requirements of the standard.

Date:

Lab Property Number(s): NAL 51464

Lab Location Code: MES-MW (obtain from Safety Officer)

Purpose of Vessel(s): Provide LN2 & GN2 for operational support of L.A.C. equipment (experiment E706)

Vessel Capacity/Size: 9000 Gal. 312" tall - 120" dia. vertical dewar

Normal Operating Pressure (OP) 20-45 PSIG

MAWP-OP = 33 PSIG

Is the above enough to provide relief cracking pressure tolerance plus system uncertainty tolerance per M-9. Yes

As an option, provide a photo of the entire vessel in the Appendix.

List the numbers of all pertinent drawings and the location of the originals. (Append copies).

| Drawing # | Location of Original |
|---|---|
| 2220.1-ME-183293 (Sheet 2) | RD/Cryogenics Dept. 11th Fl. |
| System Venting Schematic | See Text |
| | |
| | |
| | |
| | |

5.2 **Design Verification**

Does the vessel(s) have a U stamp? Yes X No ______. If "Yes", fill out data below and skip page 3; if "No", fill out page 3 and skip this page.

Staple photo of U stamp plate below.

Copy "U" label details to the side if photo is not clear of if copies are unreadable.

Copy data here:

S/N PN 51464

NB 8602 U $RT^{W}$ 2

VLS 9000 Inner Vessel

Only duplicate

Max. of contents 104963#

MAWP 78 PSIG @ -320°F min

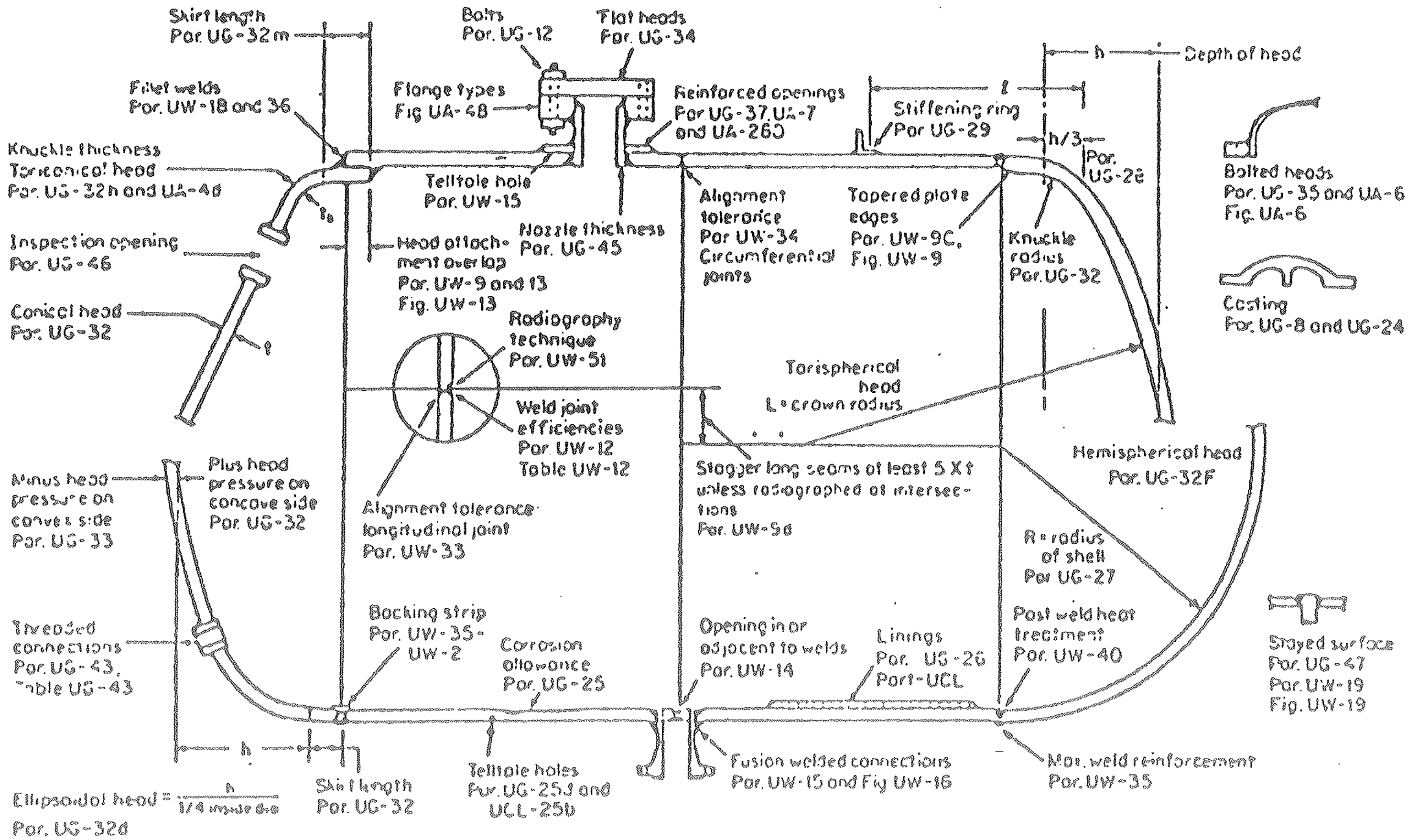
allow temp. Ser. No. 106-

Year built 1985, Tare Wt.26000#



Revised October 1982

On the sketch below, circle all applicable sections of the ASME code per Section VIII, Division I. List the results of all calculations. (Insert copies of calculations in the appendix).




## Summary of ASME Code

| Item | Reference ASME Code Section | CALCULATION RESULT (Required thickness or stress level vs. actual thickness or calculated stress level) |
|---|---|---|
| | | vs. |
| | | vs. |
| | | vs. |
| | | vs. |
| | | vs. |

If this vessel is exceptional or had exceptional parts, list their details under 5.6. Yes______ No__________



Revised October 1982

5.3 System Venting. Provide the system schematic in the Appendix, if the vessel safety is system sensitive.

Is it possible to isolate the relief valves by a valve from the vessel?

Yes______ No x

If "Yes", the system must conform to M-5. Provide an explanation on the appended schematic. (An isolatable vessel, not conforming to M-5 violates the Standard.)

Is the relief cracking pressure set at or below the M.A.W.P.?

Yes x No______ Actual setting 50 PSI
(A no response violates the Standard.)

Is the pressure drop of the relief system at maximum anticipated flow such that vessel pressure never rises above the following? (UG 125)

Yes x No______ 110% of MAWP (one relief)
116% of MAWP (multiple reliefs)
121% of MAWP (unexpected heat source)

Provide test or calculational proof in the Appendix.
(Non-conforming pressure rises violate the Standard.)

List of reliefs and settings:

| Manufacturer | Relief | Setting | See text SCFM Air Flow Rate | Orifice Size |
|---|---|---|---|---|
| Fike Burst Disk | CPU UT Union Type | 85 PSIG | 1499.98@179.1R | 1" |
| ANDERSON-GREENWOOD | 81B88-8 | (see Text) 50 PSIG | 493.04@179.1R | 0.196 |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Is the relief device an ASME stamped device? Yes X No ______

5.4 Operating Procedure

Is an operating procedure necessary for the safe operation of this vessel?

Yes______ No X . If "Yes", please append.

5.5 Welding Information

Has the vessel been fabricated in a Fermilab shop? Yes______ No x

If "Yes", append a copy of the welding shop statement of welder qualification and a copy of the Welding Procedure Specification (WPS) used to weld this vessel.

5.6 Exceptional, Existing, Used, and Non-Manned Area Vessels

Is this vessel or any part thereof in the above categories? Yes______ No X

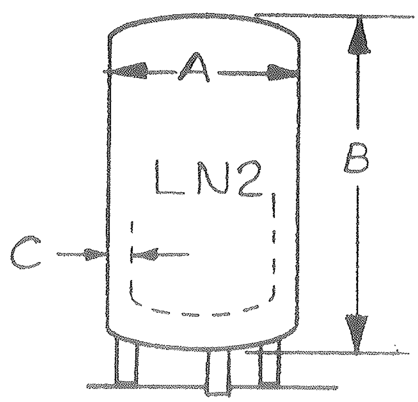
If "Yes", follow the Engineering Note requirements for documentation in free form below.

## SYSTEM DESCRIPTION

This $LN_2$ dewar is an ASME certified dewar. It is a vertical dewar to be used for L.A.C. (E706) support of operations.

The relief system is a dual system which can be non-isolatably switched from one burst disk/relief valve system to another identical system. Refer to the attached schematic. The dewar is founded outside, just east of the MW Detector Hall.

## PHYSICAL DATA




A = 120 inches
B = 312 inches
C = 10.5 inches

Inner to outside vessel distance is: 10.5 inches.

Volume = 9000 Gal $LN_2$ = 1213 cu ft

Since inner vessel drawings are not available, the outer vessel surface area will be used:

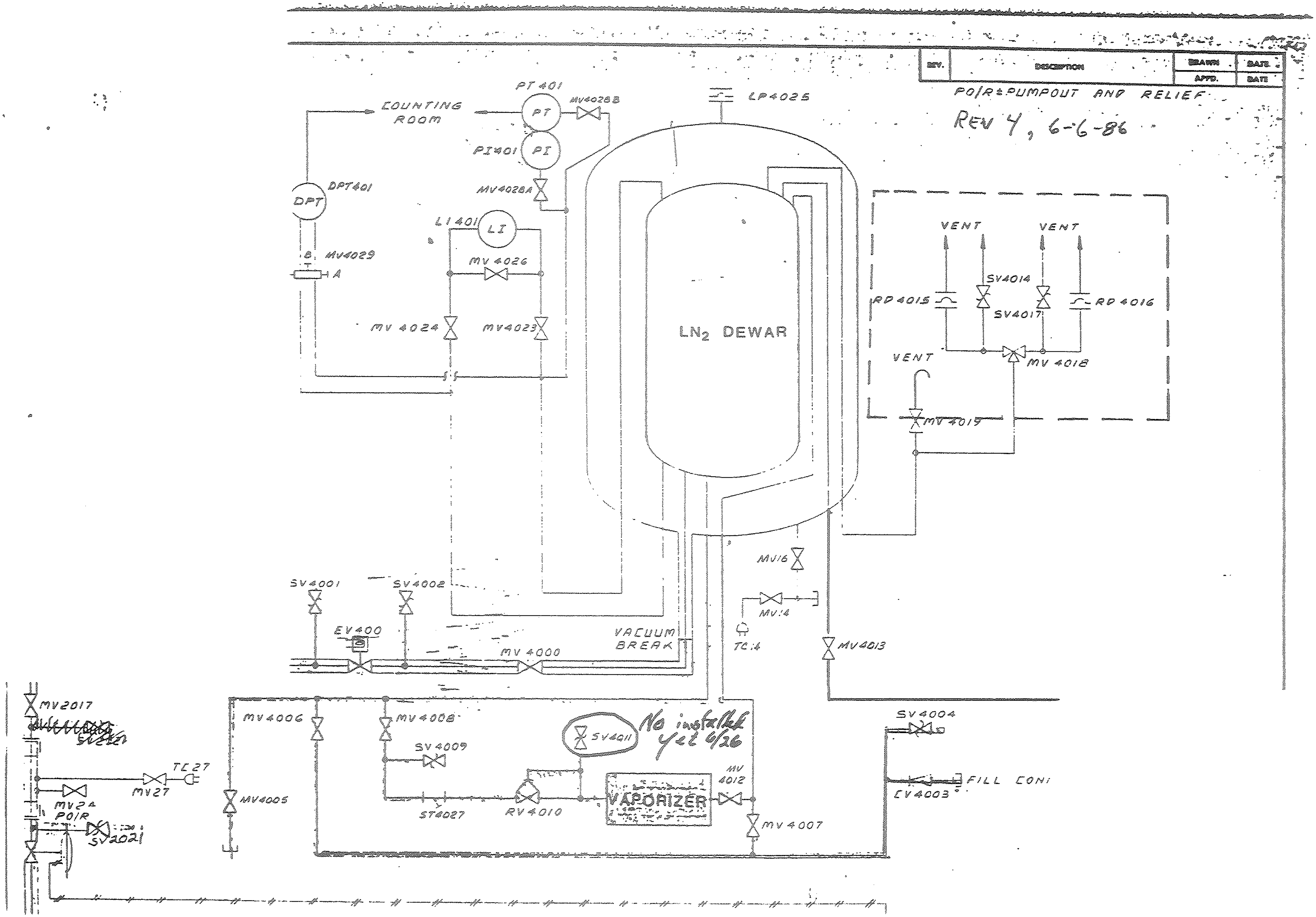
A = 974 sq ft of surface of the outer vessel.

NOTE: The following value is used for the relief capacity calculations:

Fx MAWP + 14.7 = P absolute

F = CGA Factor (1.21, 1.16, etc.)

This is conservative.


REV.
DESCRIPTION
DRAWN
DATE
APPD.
DATE
POIR PUMPOUT AND RELIEF
REV 4, 6-6-86
LP4025
COUNTING ROOM
PT 401
PT
MV4028B
PI401
PI
MV4028A
DPT401
DPT
B
MV4029
A
LI 401
LI
MV 4026
MV 4024
MV4023
LN2 DEWAR
VENT
VENT
SV4014
RD 4015
SV4017
RD 4016
VENT
MV 4018
MV 4019
MV16
MV14
TC14
MV4013
SV4001
SV4002
EV400
MV 4000
VACUUM BREAK
MV2017
MV4006
MV4008
SV4009
SV4011
No installed yet 6/26
MV 4012
VAPORIZER
MV 4007
SV4004
FILL CONN
CV4003
TC27
MV27
MV24
POIR
SV2021
MV4005
ST4027
RV4010

## RELIEF VALVE DATA

The relief valve is ASME certified, and stamped as follows:

Anderson-Greenwood USA, Inc.
Houston, Texas U.S.A.

Series 80 SRV

| | |
|---|---|
| Set pressure: | 78 psig |
| Serial number: | 86/03953 NB UV |
| Part No.: | 81B88-8 |
| Capacity: | 295 SCFM air |
| Size: | 1 inch Trim: To 0 |

This valve is to be reset to: 50 psig = set pressure

Valve orifice area is: A = 0.196 sq inch

## BURST DISK DATA

The Fike burst disk is stamped as follows:

| | |
|---|---|
| Size: | 1 in |
| Type: | CPV UT |
| Serial Number: | NA |
| Material: | 316 AL 316 VI |
| Burst Pressure: | 85 psig @ 72°F |

The mating union is ASME certified.

# CAPACITY SUMMARY

| CAPACITY REQUIRED: | CAPACITY AVAILABLE | LOCATION OF COMPUTATIONS |
|---|---|---|
| External jacket, 18.10 sq in. | 45.66 sq in. | Section 4 |
| Fire condition 549.5 SCFM air | 1993 SCFM air | Section 8 |
| Tanker overfill protection 100 GPM @ 1.16 MAWP | 361.70 GPM | Section 5 |
| Trapped volumes must be less then 38 feet long | Longest run less then 38 feet long | Section 6 |

## LOSS OF VACUUM

$$Q_A = \frac{(130 - t)}{4(1200 - t)} G_i UA$$ Per CGA S1.3-1980, Sec. 4.9.1.1

$G_i$ = 10.2
@ 110% MAWP (100.5 psia)

$t$ = -282.6 °F (sat vapor)

$$U = \frac{\text{K pearlite @ 100°F sat lading}}{\text{thickness (= 10.5")}}$$

K = 26 E-3 BTU/HR-FT-°F (from LNG Materials and Fluids Data Handbook)

U = 29.71 E-3 BTU/HR-FT$^2$-°F

A = Since no drawings of the inner vessel are available, the external jacket surface will be used

= 974 ft$^2$

$$Q_{SA} = \frac{(130 + 282.6)}{4(1200 + 282.6)} 10.2\ (29.7\ E\text{-}3)(974) =$$

$Q_{SA}$ = 20.72 SCFM air

## FIRE CONDITION

$Q_{SA} = G_i\ UA^{0.82}$ per CGA S1.3-1980, Sec. 5.3.5

$$U = \frac{\text{K pearlite @ conditions}}{\text{thickness (= 10.5 in)}}$$

K = 167 E-3 BTU/HR-FT-°R (LNG Materials & Fluids Data Handbook)

$$U = \frac{167\ E\text{-}3}{10.5/12} = 190.85\ E\text{-}3\ \frac{BTU}{FT^2 HR °F}$$

A = 974 ft$^2$

$G_i$ = 10.2

$$Q_{SA} = 10.2\ (190.85\ E{-}3)\ (974)^{0.82}$$

$$\underline{Q_{SA} = 549.5 \text{ SCFM air required}}$$

## OUTER VESSEL RELIEF

**Required area:**

A = 2.4 E-4 $in^2/lb$-$H_2O$cap x Density $H_2O$ x Volume

Density $H_2O$ = 8.36 lb/gal of $H_2O$

Volume = 9000 gal

A = 2.4E-4(8.36)(9000) = 18.1 $in^2$

**A = 18.1 $in^2$ required**

**Actual area:** $A_t$

Dia = 7.625 in, flow area of the relief device

$A_t$ = 45.66 $in^2$, area of the relief device

$A_t > A$ 45.66 > 18.1

The outer vessel relief device is a lift plate tested by the manufacturer to lift at 1 psig.

## LIQUID CAPACITY

Assume: (1) Tanker delivers 100 gpm liquid to a full dewar at the burst disk bursting pressure 99.696 psia, this is 85 psig or 109% of MAWP.

(2) The dewar must relieve 100 gpm at less then 116% MAWP or 105.177 psia of saturated liquid. The flow will be calculated at 99.696 psia. This is the rupture pressure of the burst disk; i.e., at a pressure drop of about 5.5 psid in the inlet piping.

The liquid flow of the relief valve is 41.53 gpm, and the burst disk flow is 320.17 gpm. Ref: 10,11.

Total flow is 361.70 gpm or 3.6 times the requirement (100 gpm)

Specific values used are tabulated on the following page. Eq. (3) of Section A was applied to the relief valve and Eq. (3) of Section B was applied to the burst disk.

######## RELIEF VALVE FLOWS TYPE= 80 #######

| | | |
|---|---|---|
| PRESSURE= | 99.696 | PSIA |
| BACKPRESSURE= | 14.696 | PSIA |
| PE/P= | .14741 | |
| REYNOLDS NUMBER= | .24204E+07 | |
| VISCOSITY CORR= | 1.0000 | |
| AREA= | .19600 | SQIN |
| VALVE COEFF= | .81600 | |

FLOW RATE (GPM)= 41.532
FLOW RATE (LB/SEC)= 4.0729
*** FLOW IS A LIQUID FLOW ***

STATE VARIABLES FROM NBS, PSIA, RANKINE, ** NITROGEN **
CUFT/LBM, LBF/FT-SEC, BTU/LBM, BTU/LBM-DEG, FT/SEC, VAPOR, LIQUID

| | | | |
|---|---|---|---|
| PRES, TEMP, SPEC VOL, VISC= | 99.696 | 176.86 | .56862 VAPOR ft³/lb |
| | LIQUID .22904E-01 | .47277E-05 | .51468E-04 |
| HG, HF, HFG, UG, UF, UFG= | 37.766 | -32.942 | 70.708 |
| | 27.276 | -33.364 | 60.640 |
| CPG, CPF, CVG, CVF, SPEED= | .34001 | .54256 | .19931 |
| | .22376 | 601.99 | 2085.4 |

***********************************************************************

REF 3
EQ 3, SEC A

######## BURST DISK FLOWS ########

| | | |
|---|---|---|
| PRESSURE= | 99.696 | PSIA |
| BACKPRESSURE= | 14.696 | PSIA |
| PE/P= | .14741 | PSIA |
| REYNOLDS NUMBER= | .93209E+07 | |
| FRICTION FACTOR= | .13846E-01 | |
| RESISTANCE FACTOR= | .98130 | |
| THROAT DIAMETER= | 1.0000 | INCHES |

FLOW RATE (GPM)= 320.17
FLOW RATE (LB/SEC)= 31.398
*** FLOW IS A LIQUID FLOW ***

STATE VARIABLES FROM NBS, PSIA, RANKINE, ** NITROGEN **
CUFT/LBM, LBF/FT-SEC, BTU/LBM, BTU/LBM-DEG, FT/SEC, VAPOR, LIQUID

| | | | |
|---|---|---|---|
| PRES, TEMP, SPEC VOL, VISC= | 99.696 | 176.86 | .56862 VAPOR ft³/lb |
| | LIQUID .22904E-01 | .47277E-05 | .51468E-04 |
| HG, HF, HFG, UG, UF, UFG= | 37.766 | -32.942 | 70.708 |
| | 27.276 | -33.364 | 60.640 |
| CPG, CPF, CVG, CVF, SPEED= | .34001 | .54256 | .19931 |
| | .22376 | 601.99 | 2085.4 |

***********************************************************************

REF 4
EQ 3, SEC B

# TRAPPED VOLUME

The following pipe sizes may be considered a trapped volume:

1-1/4 Sch 40 pipe

1-1/4 Sch 10 pipe — Outer Surface Area * A = .434 $ft^2/ft$ for these sizes.

1-1/4 Sch 5 pipe

$$\text{Heat flux} = 600 \frac{BTU}{HR\text{-}FT^2}$$

This is more then "Barron's" 575 $BTU/HR\text{-}FT^2$

$$Q = 600 \frac{BTU}{HR\text{-}FT^2} \times .434 \frac{ft^2}{ft}$$

$$Q = 260 \frac{BTU}{HR\text{-}FT}$$

Heat flux per ft of length

Latent heat of vap. @ 1 atmosphere

ΔHFG = 85.86 BTU/lbm , RVCAP = relief capacity

$$RVCAP = 260 \frac{BTU}{HR\text{-}Ft} * \frac{lbm}{85.86\ BTU} = 3.0328 \frac{lbm}{HR\ Ft}$$

$$RVCAP = 50.547\ E\text{-}3 \frac{lbm}{min\text{-}ft}$$

mass flux per ft of length required

Need RVCAP = 641.9 E-3 SCFM air/ft of length.

RV's are set at 350 psig and are built into the valve bodies. The capacity is 25 SCFM air, and can relieve 38 ft of pipe, and longest run is less then 10 ft.

## PIPE HOOP STRESS AND DESCRIPTION

From Piping Engineering, Chemetron Corp, 1969 tabulated ASME/ANSI values are used. Piping joints are butt welded, of 304 SS where Y = 0.4 and S < 20000 psi. Sizes range from 1/2" Sch 10 to 1-1/4" Sch 40.

For no corrosion allowance:

| | | |
|---|---|---|
| 1/2" Sch 10 | * | 3716 psig max. |
| 1/2" Sch 10 | * | 4996 psig max. |
| 1" Sch 5 | * | 1792 psig max. |
| 1" Sch 10 | * | 3080 psig max. |
| 1" Sch 40 | * | 3810 psig max. |
| 1-1/4" Sch 5 | * | 1410 psig max. |
| 1-1/4" Sch 10 | * | 2408 psig max. |
| 1-1/4" Sch 40 | * | 3136 psig max. |

These pressures will never develop in the dewar system.

The connecting piping is all welded, of the proper schedule, and trapped (isolatable) volumes are relieved through relief valves.

This dewar does not yet have a vent pipe downstream of relief valves but the discharge is directed downward, close to the ground, and away from the dewar, associated equipment, and people.

# RELIEF VALVE AND BURST DISK CAPACITY

The effects of pipe friction on a compressible flow could be considered, but this type of calculation is hardly justified given the obvious safety factor of this relief system. The computation involving friction has been made but will not be presented.

Taking the dewar at 1.21 MAWP, as required by CGA-S1.3 Fire Condition, or

PD = 109.0759 psia

and assuming a 10 psid drop in the inlet and outlet piping for both the relief valve and rupture disk leads to a device inlet pressure of P = 99.0759 psia, and an exit pressure of PE = 24.696 psia. A complete listing of the fluid properties obtained from Reference 5 follows on the next page. Important values are:

P = 99.0759 psia     T = 179.1362 R

VG = 0.585475 $ft^3/lbm$

K = Cp/Cv = 1.68341

###### SATURATED NITROGEN ######    REF 5

| | | | | |
|---|---|---|---|---|
| CRITICAL POINT | 492.9953 | PSIA | 227.2680 | RANKINE |
| TRIPLE POINT | 1.807602 | PSIA | 113.6700 | RANKINE |

FOR PRES= 109.0759 PSIA TEMP= 179.1362 RANKINE
FOR TOTAL SPEC VOLUME= .5197786 CU FT/LBM
QUALITY= 1.000000 G= VAPOR F= LIQUID

| | | | | |
|---|---|---|---|---|
| VG, VF, VFG= | .5197786 | .2315933E-01 | .4966193 | CU FT/LBM |
| HG, HF, HFG= | 37.84615 | -31.69381 | 69.53996 | BTU/LBM |
| UG, UF, UFG= | 27.35415 | -32.16129 | 59.51544 | BTU/LBM |
| SG, SF, SFG= | 1.193988 | .8055740 | .3884135 | BTU/LBM-R |
| CPG, CPF= | .3484799 | .5494510 | BTU/LBM-R | |
| CVG, CVF= | .2006197 | .2235270 | BTU/LBM-R | |
| THERMAL COND G, F = | .6597593E-02 | .5718352E-01 | BTU/FT-HR-R | |
| PRANDTL NUMBER G,F= | .9150277 | 1.713055 | | |
| VISCOSITY G, F= | .4812155E-05 | .4952342E-04 | LBF/FT-SEC | |
| SONIC VELOCITY G,F= | 602.0702 | 2031.647 | FT/SEC | |

VAPOR K = CP/CV = 1.73702

###### NITROGEN ######

| | | | | |
|---|---|---|---|---|
| CRITICAL POINT | 492.9953 | PSIA | 227.2680 | RANKINE |
| TRIPLE POINT | 1.807602 | PSIA | 113.6700 | RANKINE |

FOR PRES= 99.07595 PSIA TEMP= 179.1362 RANKINE

| | | | | |
|---|---|---|---|---|
| SPECIFIC VOLUME= | .5854725 | CU FT/LBM | | |
| H, U, S= | 38.57813 | 38.46978 | 1.203776 | BTU/LBM-S(R) |
| CP, CV = | .3328475 | .1977221 | BTU/LBM-R | |
| THERMAL COND= | .6462785E-02 | BTU/FT-HR-R | | |
| PRANDTL NUMBER= | .8858314 | | | |
| VISCOSITY= | .4777745E-05 | LBF/FT-SEC | | |
| SONIC VELOCITY= | 609.3510 | FT/SEC | | |

K = CP/CV = 1.68341

For the relief valve, applying Eq. 1, Section A, and Reference 1, leads to a sonic flow rate of:

493.04 SCFM or 0.71719 lb/sec (relief valve)

For the burst disk, applying Eq. 1, Section B and Reference 2, leads to a sonic flow of:

1499.98 SCFM or 2.1819 lb/sec (burst disk)

A complete listing of the inputs and results are given on the next page. Important values are:

relief valve: nozzle coefficient - 0.816
area of orifice - 0.196 sq in
burst dist: throat dia - 1 inch

Combined Capacity: 1993.02 SCFM, air

8.5

******** RELIEF VALVE FLOWS TYPE= 80 *******

EQ 1, SEC A
REF 1

| | | |
|---|---|---|
| PRESSURE= | 99.076 | PSIA |
| BACKPRESSURE= | 24.696 | PSIA |
| PE/P= | .24926 | |
| SPEC HEAT RATIO= | 1.6834 | |
| PCRITICAL= | .48478 | |
| TEMPERATURE= | 179.14 | DEGREES RANKINE |
| SPECIFIC VOLUME= | .58547 | CU FT/LBM |
| EXPANSION COEFF= | 378.86 | |
| AREA= | .19600 | SQIN |
| ASME VALVE COEFF= | .81600 | |

FLOW RATE (SCFM)= 493.04
FLOW RATE (LB/SEC)= .71719
*** FLOW IS SONIC ***

******** BURST DISK FLOWS ********

EQ 1, SEC B
REF 2

| | | |
|---|---|---|
| PRESSURE= | 99.076 | PSIA |
| BACKPRESSURE= | 24.696 | PSIA |
| PE/P= | .24926 | |
| SPEC HEAT RATIO= | 1.6834 | |
| PCRITICAL RATIO= | .48478 | |
| TEMPERATURE= | 179.14 | DEGREES RANKINE |
| SPECIFIC VOLUME= | .58547 | CU FT/LBM |
| THROAT DIAMETER= | 1.0000 | INCHES |

FLOW RATE (SCFM)= 1499.98
FLOW RATE (LB/SEC)= 2.1819
*** FLOW IS SONIC ***
*** FLOW IS SONIC ***

## RELIEF VALVE FLOW RATE

(Anderson-Greenwood Series 80)

From the AGCO catalog the equation:

$$W\ (lb/hr) = CKAP_1 \left(\frac{T}{ZM}\right)^{1/2}$$

can be converted so that real fluid properties may be used. Since

$$Z = \frac{P\nu}{RT},\quad R = \frac{UR}{M},\quad UR = 1545\ \frac{ft\text{-}lb}{mol\text{-}R},\quad \text{then } Z = \frac{P\nu}{MT}\ \frac{144}{1545}$$

Converting also to lb/sec leads to:

(1) $W = 909.874\ E\text{-}6\ C\ K_s A\ (P_1\ \rho_1)^{1/2}$

This is for sonic flow, i.e., $PE/P_1 \leq (2/k+1)^{k/k-1}$, where PE is the exit pressure,

and

$$C = 520\ K \left\{ \left(\frac{2}{k+1}\right)^{\left(\frac{k+1}{k-1}\right)} \right\}^{1/2}$$

Ref: API RP-520, Barron, AGCO. Text Books, ASME

C is the expansion factor for sonic flow where $K = C_p/C_v$

A = orifice area ($in^2$)

$K_s$ = ASME nozzle coefficient

= 90% $K_D$ actual

$P_1$ = inlet pressure (psia)

$\rho_1$ = inlet density ($lb/ft^3$)

Also, from the AGCO catalog, API-RP-520, ASME, and a few text books, an equation, converted the same way as Eq. (1), would be:

(2) $W = 668.756\ E\text{-}3\ C\ K_s\ A\ (P_1\ \rho_1)^{1/2}$ (lb/sec)

This is for subsonic flow, i.e. $PE/P_1 > (2/k+1)^{k/k-1}$

where

$C = \{K/K-1\ [(PE/P_1)^{2/K} - (PE/P_1)^{K+1/K}]\}^{1/2}$, the expansion factor

$K = Cp/Cv$

$K_S$ = ASME nozzle coefficient

= 90% $K_D$ actual

A = orifice area ($in^2$)

PE = exit pressure (psia)

$P_1$ = inlet pressure (psia)

$\rho_1$ = inlet density ($lb/ft^3$)

An equation for liquid flow from the AGCO catalog or API RP-520 would be:

$$Q(gpm) = \frac{38 * K_S\ K_p\ K_W\ C}{\sqrt{G}} \qquad (P_1 - P_2)^{1/2}\ A$$

As before, since tables are used for properties, and since $K_p$ and $K_v$ can be taken as 1.00 for conventional valves, the equation can be rewritten as

(3) $W\ (lbs/sec) = 418.0348\ E{-3} * C * K_S * A\ [\rho(P_1 - P_2)]^{1/2}$

$K_p$ = overpressure correction factor

$K_w$ = backpressure correction factor

$R_e$ = Reynold's number

Where C is the viscosity correction factor taken as 1.00 for $R_e \geq 100000$. Since C is a function of the $R_e$ it is necessary to approximate the proper value for $R_e < 100000$ and iterate for the correct value. Five linear equations are used for the calculation depending on $R_e$.

This equation can also be found in API RP-520, Crane, and several other references. It has been checked for series 80 valves.

Note that values obtained through the use of equations (1), (2), or (3) will not be identical to the cataloged values since the actual properties of the real gas are used. The ideal, isentropic 'properties' are not generally the same, especially over ranges of pressure near the saturation line.

The FTN5 subroutine "SAT PRES", D. Burke, 1985, is one source of saturation properties for argon, nitrogen, and oxygen (also "SAT TEMP", D. Burke, 1985). This subroutine is a converted form of the NBS program "FLUIDS", a generally accepted routine.

For series 80 and 90 RV's, the subroutine "AGRVIA", D. Burke, 1985, calculates flow rates for input values of PE and $P_1$ using saturation properties obtained from "SAT PRES". The liquid flows for series 80 valves computed by "AGRVIA", have been checked against the manufacturers values, but this has not been done for series 90 RV's.

# BURST DISK FLOW RATE

An appropriate equation for frictionless flow through a burst disk is from Fike.

For sonic flow:

1) $325.57306 \text{ E-}3 \ d^2 \ (2/k+1)^{1/k-1} \ [P_1 \ \rho_1 \ (k/k+1)])^{1/2} = W$ (lb/sec)

For subsonic flow:

2) $325.57306 \text{ E-}3 \ d^2 \ \{P_1 \ \rho_1 \ [(PE/P_1)^{2/k} - (PE/P)^{k+1/k}]\}^{1/2} = W$ (lb/sec)

Flow is sonic if

$PE/P \leq (2/k+1)^{k/k-1}$ and the mass flow becomes constant.

Flow a liquid flow:

(3) $525.23 \text{ E-}3 \ d^2 \ (1/\kappa)^{1/2} \ [P_1 \ \rho_1 \ (1 - PE/P)]^{1/2} = W$ (lb/sec)

Reference: Crane Technical Bulletin No. 410

NOTE: These equations are modified so that the real properties, not the ideal gas properties can be used. This was done by noting that the Fike equation should have included the compressibility factor, z. Then $z = PV/RT$ is substituted into the equation. (See Section A.)

where $P_1$ = inlet pressure (psia)

PE = back pressure (psia)

$\rho_1$ = throat density ($lb/ft^3$)

K = ratio of spec heats, $Cp/Cv = k$

d = diameter of the disk (inches)

$\kappa = f \ (L/D) + \kappa_1$

f = the friction factor

L/D = 75 for disk and safety head, reference "BS & B, Rupture Disk and Safety Head Technology"

$\kappa$ = loss of the form $\kappa \ v^2/2g$

$\kappa_1$ = 0, since the flow calculation includes only the disk and safety head.

Since the liquid calculation includes the friction factor, an iterative calculation is made. The calculations are made by applying "NOZZLBD", D. Burke, 1985, "SAT PRES", D. Burke, 1985 - for the fluid properties, and "FRIC", D. Burke, 1985, for the friction factor.

## REFERENCES

1) Program "AGRV2A", D. Burke, evaluates flow rates for series 80 and series 90 Anderson-Greenwood relief valves.

2) Program "BURSD1A", D. Burke, evaluates flow rates for burst disks.

3) Program "AGRV1A", D. Burke, evaluates flow rates for series 80 and 90 Anderson-Greenwood relief valves. The saturated properties are automatically evaluated.

4) Program "TSTBUR2", D. Burke, evaluates flow rates for burst disks. The saturated properties are automatically evaluated.

5) Program "PROPSA", D. Burke, evaluates properties using "NBS", D. Burke. "NBS" is from the National Bureau of Standards program "FLUIDS".

MVE Cryogenics

# FORM U-1A MANUFACTURER'S DATA REPORT FOR PRESSURE VESSELS

D.1

(Alternative Form for Single Chamber, Completely Shop-Fabricated Vessels Only)
As Required by the Provisions of the ASME Code Rules, Section VIII, Division 1

Form 2129R

1. Manufactured and certified by MINNESOTA VALLEY ENGINEERING, 407 7th St. NW; NEW PRAGUE MN. 56071
(Name and address of manufacturer)

2. Manufactured for Fermi National Accelerator Labs, Batavia, IL 60510
(Name and address of purchaser)

3. Location of installation Fermi National Labs, Batavia, IL 60510
(Name and address)

JUN -3 A8:34 REC. FERMI CONTR.

4. Type VLS 9000 (Horiz. or Vert. Tank) 106 (Mfg's. Serial No.) NA (CRN) 143292 (Drawing No.) 8602 (Nat'l. Bd. No.) 1985 (Year Built)

5. The chemical and physical properties of all parts meet the requirements of material specifications of the ASME BOILER AND PRESSURE VESSEL CODE. The design, construction, and workmanship conform to ASME Rules, Section VIII, Division 1 1983 to 5-84 (Addenda (Date)) NA (Code Case Nos.) LOW TMP. SVC. UW2B. UHA51 (Special Service per UG-120(d))

6. Shell: SA240-304 (Mat'l (Spec. No., Grade)) .288 (Nom. Thk. (in.)) 0 (Corr. Allow. (in.)) 8'-6 (Diam. I.D. (ft. & in.)) 18'-9 (Length (overall) (ft. & in.))

7. Seams: WLD. DBL. BUTT (Long. (Welded, Double, Single, Lap, Butt)) FULL (R.T. (Spot or Full)) 100% (EFF.%) NA (H.T. Temp. (F)) NA (Time (hr.)) WLD. SGL. BUTT (Girth (Welded, Double, Single, Lap, Butt)) PART. (R.T. (Spot, Partial, or Full)) 2 (No. of Courses)

8. Heads: (a) Matl. SA240-304 (Spec. No., Grade) (b) Matl. SA240-304 (Spec. No., Grade)

| | Location (Top) Bottom, Ends) | Minimum Thickness | Corrosion Allowance | Crown Radius | Knuckle Radius | Elliptical Ratio | Conical Apex Angle | Hemispherical Radius | Flat Diameter | Side to Pressure (Convex or Concave) |
|---|---|---|---|---|---|---|---|---|---|---|
| (a) | TOP | .288 | 0 | NA | NA | 2:1 | NA | NA | NA | CONCAVE |
| (b) | BT'M | .288 | 0 | NA | NA | 2:1 | NA | NA | NA | CONCAVE |

If removable, bolts used (describe other fastenings) NONE
(Matl., Spec. No., Gr., Size, No.)

9. MAWP 78 psi at max. temp. 100 °F
Min. temp. (when less than -20° F) -320 °F. Hydro., pneu., or comb. test pressure 133 psi

10. Nozzles, inspection and safety valve openings:

| Purpose (Inlet, Outlet, Drain) | No. | Diameter or Size | Type | Matl. | Nom. Thk. | Reinforcement Mtl. | How Attached | Location |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| LW. BF | 4 | 2.000D | W.E | SA269-TP304 | .218 | NA | WELDED | NA |
| TF. V | | | | | | | | |
| GPH. LPL | 2 | 0.500D | W.E. | SA249-TP304 | .083 | NA | WELDED | NA |
| FT | 1 | 1.000D | W.E. | SA249-TP304 | .128 | NA | WELDED | NA |
| GU | 1 | 1.560D | W.E. | SA312-TP304 | .159 | NA | WELDED | NA |
| HYDRO | 2 | 1.560D | CPLG. | SA182-F304 | .210 | NA | WELDED | NA |
| | | | | | | | | |

11. Supports: Skirt NA (Yes or No) Lugs NA (No.) Legs NA (No.) Other STRAPS (Describe) Attached ENDS WELDED (Where and How)

12. Remarks: Manufacturer's Partial Data Reports properly identified and signed by Commissioned Inspectors have been furnished for the following items of the report: NA
(Name of part, item number, Mfg's name and identifying stamp)

Vacuum jacketed vessel for storage of liquid nitrogen, oxygen, or argon. Design pressure is 106.0psi. Inner vessel coded only
Hydro ports are plugged and seal welded.

## CERTIFICATE OF SHOP COMPLIANCE

We certify that the statements made in this report are correct and that all details of design, material, construction, and workmanship of this vessel conform to the ASME Code for Pressure Vessels, Section VIII, Division 1. "U" Certificate of Authorization No. 8377 expires JAN. 15 1986

Date 4/8/85 Co. name MINNESOTA VALLEY ENG. (Manufacturer) Signed Wm. H. Schmuck (Representative)

## CERTIFICATE OF SHOP INSPECTION

Vessel constructed by MINNESOTA VALLEY ENGINEERING at NEW PRAGUE MINNESOTA 56071

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and/or the State or Province of MINNESOTA and employed by H.S.B.I.&I. CO. of HARTFORD CT.

have inspected the component described in this Manufacturer's Data Report on 4-8, 1985, and state that, to the best of my knowledge and belief, the Manufacturer has constructed this pressure vessel in accordance with ASME Code, Section VIII, Division 1. By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the pressure vessel described in this Manufacturer's Data Report. Fruthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Date 5-1-85 Signed DuWayne R. Dosher Commissions NB-9420 MN 85-24