**12/8/2010**

# E906 Target Safety Document

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## A. INTRODUCTION

This document is the E906 Target System Safety Report. The E906 Experiment is a successor experiment to Experiment E866 and will re-use many of the designs and components that were used for that experiment. For parts of the system where designs and components are directly re-used this document will copy sections of the E866 Target System Safety Report; these sections will be noted.

The E906 target system will be located in the SeaQuest hall inside building NM4. The liquid target system consists of three stainless steel flasks. The flasks are 2.2 liters each in volume, with dimensions of 20 inches long by 3 inches in diameter. One flask holds liquid deuterium, one holds liquid hydrogen and one is empty for background measurements. One liquid flask and the empty flask share the same vacuum space; the other liquid flask is in an independent vacuum enclosure, reducing the likelihood of release of the entire 4.4 liters of liquid in case of an accident. Upper vacuum tanks are built of stainless steel. The lower sections, containing the flasks, are built of aluminum, with titanium-alloy windows. E906 will re-use many E866 vacuum components, and, at least initially, the E866 flasks.

The liquid targets are cooled by independent cryocoolers. Each cryocooler consists of a coldhead connected to a compressor package with flexible stainless steel hoses. The coldheads each cool a condenser assembly, which is connected to a flask with stainless steel tubes. The E866 cryocoolers were not re-useable, so new cryocooler systems were purchased from Cryomech, Inc. and, because of configuration differences between the old and new coldheads, new condenser assemblies were designed and fabricated.

The target temperatures are controlled with heaters on the condensers to a pressure of about 14.7 psia, slightly above atmosphere. The primary relief valves protecting the liquid flasks will have computer-controlled setpoints of about 20 psia. Backup mechanical relief valves will have setpoints of 10 psig.

The liquid targets and 3 solid targets will be mounted on a motion table built by Daedel. The targets will move horizontally into and out of the beam. A complete specification for the motion system is in Section B of this report.

The target control system, which will monitor temperatures and pressures, control condenser heater power, and control the table motion, is based on a Siemens APACS Programmable Logic Controller (PLC).

The tent design is based on calculations from E866.

## B. MAJOR SUBSYSTEMS

### Cryorefrigerators

Two cryorefrigerators, Cryomech model AL230, will be used for E906. They have a rated cooling power of 25 W at 20 K. 50-foot flexible hoses were purchased from Cryomech to connect the coldheads to the water-cooled compressor packages. These refrigerators have no controls for cooling power or temperature. We will control the condenser temperature with heaters on the condenser assembly.

Custom inserts into the hoses were purchased from Cryomech. The inserts at the coldhead ends will allow hanging loops of hose to accommodate target movement in the restricted space of the target enclosure. Inserts at the compressor ends will have pressure transducers for remote monitoring of helium pressures and reduce floor space needed to direct the hoses toward the target enclosure.

### Condenser assemblies

Condenser assemblies are shown schematically in Fig.1. Each body consists of two machined 110 copper parts brazed together. Inside dimensions of the two condenser bodies are the same, but after successful testing of the first body, a design with improved braze joints was adopted for the second. Inside each body are two cylindrical copper fins, brazed into the condenser bottom, to increase condensation area. A coil of copper tube wrapped around the upper cylinder provides pre-cooling of hydrogen gas during filling.

Vent tubing and the tubing connecting the condenser to the flask consists of ½ inch O.D. x 0.028 inch wall 304L stainless steel, with Swagelok bellows, Swagelok VCR fittings with silver-plated stainless gaskets, and Braze-tite adapters. The filling tube is ¼ inch O.D. x 0.020 inch wall 304L stainless steel, with Swagelok bellows and a machined brass connector to the pre-cool coil. All joints are brazed with 45% silver brazing material, other than vendor-welded joints in the Swagelok bellows.

### Flasks

The E866 flasks are shown in vacuum jackets in Fig. 2. Cylindrical walls are 0.003 inch 304 stainless steel and the end caps are 0.002 inch. They were pressure tested in March 2009 to ~16 psig while inside a vacuum jacket pumped to the micron level. They were then checked with a He leak chaser sensitive to ~ $10^{-9}$ stdcc/sec and no leaks were detected. New flasks with the same dimensions are being fabricated as spares. They will pass the same tests as the E866 flasks before installation.

**Vacuum Systems**

Most vacuum components used in E866 will be re-used in E906. The main new parts are the top plates which carry the refrigerators and condensers. Diffusion pumps and mechanical pump carts are being refurbished

**Tent**

Above, below and on either side of the target will be shielding blocks. Downstream of the target will be shielding blocks and the magnet FMag, which will serve as a focusing magnet for dimuon pairs and the beam dump for the primary proton beam. Upstream of the target will be a curtain to complete a target enclosure. A helium filled beam pipe will go through this curtain to reduce scattering of the proton beam. This tent will have an exhaust fan to clear hydrogen. Venting calculations, following those from E866 are given in Section K.

**Target Control System**

The E906 targets (two liquid targets ($LH_2$, $LD_2$), an empty target, 3 solid targets, and an empty solid target) will be placed on a remotely controllable translation table such that the targets can be changed between beam pulses. All instrumentation, such as temperature/pressure sensors, valves, heaters, and flow meters as well as vacuum pumps, cryo-compressors, air compressors, and water chillers will be installed inside the experimental hall. The E906/SeaQuest target control system will be placed outside the experimental hall, and will be able to remotely monitor and control the cryogenic and solid targets.

The target control system is a Siemens APACS Programmable Logic Controller (PLC) which consists of I/O modules to send/receive signals from the various target instruments such as sensors and valves, and a CPU which processes the I/O signals to determine the appropriate action needed for the safe and continuing operation of the target. Some of these actions are automated commands (interlocks) directly sent from the PLC to the target via the I/O modules, while others (such as alarms) require an operator response. The software for the PLC is written in functional block diagrams and sequential text language. The Graphical User Interface (GUI) for the target control system will be the Windows-based GeFanuc iFIX/iHistorian software which is capable of accessing the PLC process variables through a point-and-click interface in order. The system components are:

- ACM – PLC CPU. Programmable. Controls the rest of the I/O modules via the PLC MODULRAC backplane.

- Resistive Temperature Module (RTM) – An input module capable of measuring the resistance of temperature resistors with a linear calibration curve. 32 channels.
- Standard Analog Module (SAM) – Analog I/O. Can be configured for 24VDC, 0-20mA or 4-20mA input/output. 32 channels.
- Standard Digital Module (SDM) – Digital I/O. Can be configured for 24VDC digital pulse input/output. 32 channels.
- Voltage Input Module (VIM) – Voltage input. Can be configured for 0 to 5VDC, 0 to 10VDC, -5 to 5VDC, or -10 to 10VDC input. 16 channels.
- CERN signal conditioner (LHC ACR STMS1) – Converts temperature sensor resistance into 2 signal outputs:
    - Signal 1: Analog output (24VDC, 4-20mA). Scales linearly with resistance.
    - Signal 2: Voltage output. Voltage specifies the resistance range. (6V = 30 Ω to 250 Ω, 4V = 250 Ω to 2500 Ω, 2V = 2500 Ω to 25000 Ω).
- Watlow DA10-24F0-0000 SCR – Analog input (24VDC, 4-20mA). Line/Load voltage = 100 to 240V. 4-20mA input scales linearly with 0-100% throughput of load voltage (e.g 12mA = 50% throughput).

The PLC is powered by two Sola Hevi-Duty SDN-10-24-100P 24VDC/10A power supplies. An APC 2200XL (2200VA-rated) uninterruptable power supply (UPS) and SU48R3XLBP battery pack will provide AC power. With an expected load of 1000W, the UPS will continue to provide power for 2.9 hours in the event of a power outage.

**Target Motion Table**

The E906 motion table will re-use the table used for the E866 experiment, and the basic setup, therefore, will be similar to the E866 experiment. However, the motor used to drive the target table will be that of a higher torque than that used for the E866 experiment. The list below shows the items that are part of the target table:

- 1 Anaheim Automation 42D212S 1575 oz-in torque stepper motor
- 1 Anaheim Automation MLA10641 Motor Driver
- 1 Anaheim Automation PLC601USB single axis stepper motor controller

- 1 Anaheim Automation #CPL-KTR-14GS-0.375-2.0 shaft coupling
- 1 Anaheim Automation CPL-KTR-14GS-0.625-2.1 shaft coupling
- 1 Anaheim Automation CPL-KTR-SPDR-14GS-98R coupling spider
- 1 Encoder Connection EC-E57-S12 5VDC encoder
- 3 Hamlin 5802 proximity switches mounted on the table frame and a magnet mounted on the table.

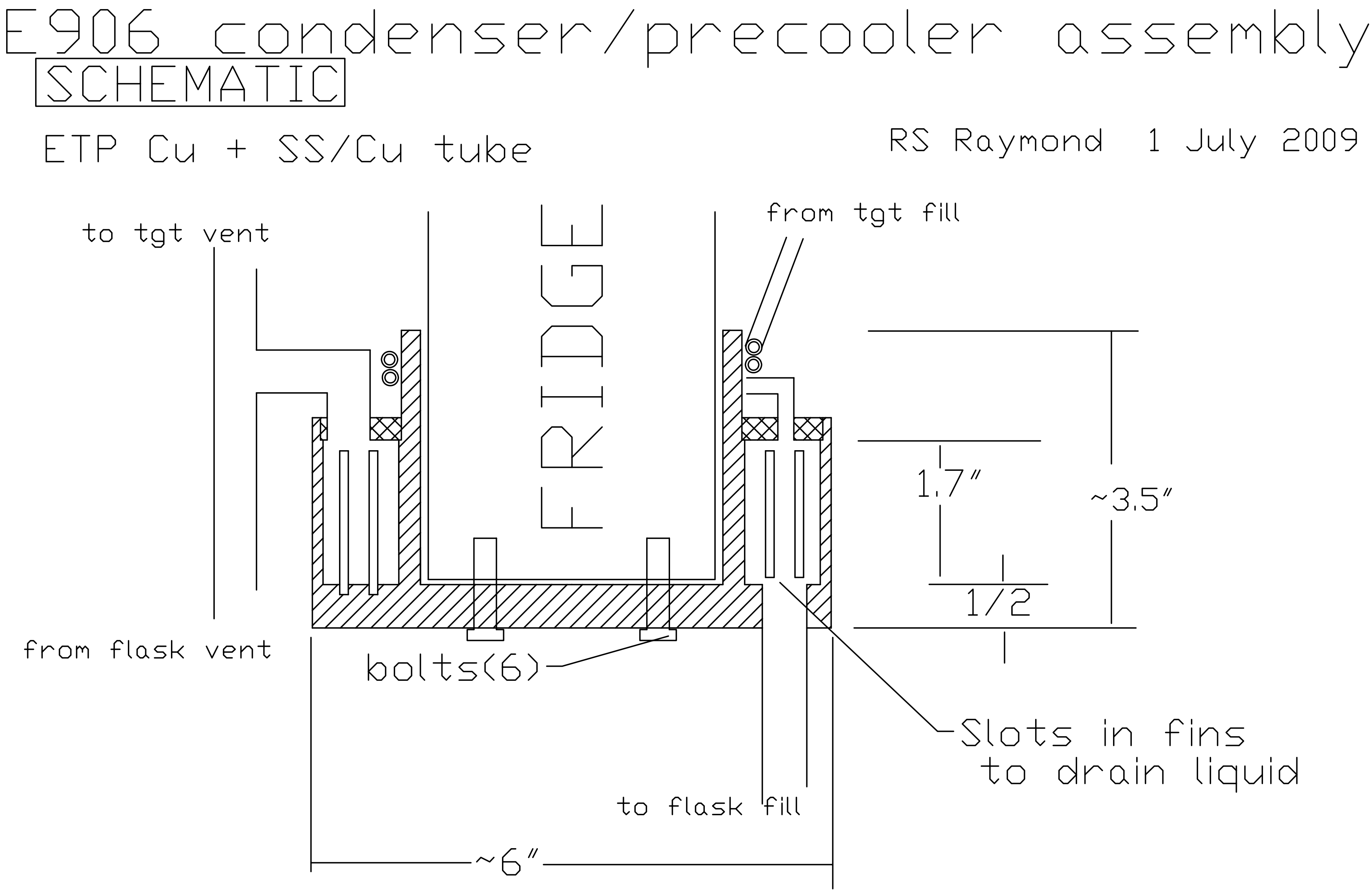
E906 condenser/precooler assembly
SCHEMATIC
ETP Cu + SS/Cu tube
RS Raymond 1 July 2009
to tgt vent
from tgt fill
FRIDGE
from flask vent
bolts(6)
1.7"
~3.5"
1/2
Slots in fins
to drain liquid
to flask fill
~6"

Figure 1


50 WATT REFRIGERATOR
.500 O.D. x .049 WALL STAINLESS STEEL TUBING
3 1/2 SCH. 10 STRAIGHT TEE
TARGET ADJUSTMENT SPIDER
TARGET TRANSITION BLOCK
TARGET FLASK 3.00 I.D. x .003 THK. STAINLESS STEEL
VACUUM JACKET 5.00 O.D. x .125 WALL ALUMINUM TUBING
SUPERINSULATION 20-LAYERS/INCH
4.25 DIA. x .0055 THK. TITANIUM ALLOY WINDOW
4.25 DIA. x .0055 THK. TITANIUM ALLOY WINDOW
BEAM CENTERLINE
TARGET HEMISPHERICAL HEAD .002 THK. STAINLESS STEEL
TARGET HEMISPHERICAL HEAD .002 THK. STAINLESS STEEL
TARGET SUPPORT/FILL ADAPTER STAINLESS STEEL
9.00
4.00
20.00
23.25
1.13 REF.
TARGET SUPPORT
BASE PLATE
PARALLEL PLATE RELIEF
(INSTALLED ON BOTH LIQUID TARGETS)
TARGET TRANSITION BLOCK
A
A
VIEW A-A
REV.
DESCRIPTION
DRAWN
APPROVED
DATE
DATE
ITEM NO.
PART NO.
DESCRIPTION OR SIZE
QTY. REQ.
PARTS LIST
UNLESS OTHERWISE SPECIFIED
.XX
.XXX
ANGLES
±
±
±
ORIGINATOR
D. ALLSPACH
6-14-95
DRAWN
B. CYKO
6-14-95
CHECKED
APPROVED
USED ON
MATERIAL
1. BREAK ALL SHARP EDGES .015 MAX.
2. DO NOT SCALE DRWG.
3. DIMENSIONING IN ACCORD WITH ANSI Y14.5M-1982 STD'S.
4. ALL DIMENSIONS ARE IN INCHES.
MAX. ALL MACHINED SURFACES
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
RD/MECHANICAL SUPPORT DEPT.
E-866
TARGET CROSS SECTION
SCALE
1/2
DRAWING NUMBER
9205.100-MD-58635
SHEET NO.
1 OF 1
REV.
Created: 11:09:15 on 23-07-08 (D-M-Y)
By: mateski
State: 1-INITIAL

Figure 2

# C. VALVE AND INSTRUMENT LIST/FLOW DIAGRAM

| E906 VALVE AND INSTRUMENTATION LIST | | | | | | |
|---|---|---|---|---|---|---|
| **Designation** | **Function** | **Manufacturer** | **Model** | **Range/Max working Press.** | **Size/Output** | **Notes** |
| **Check Valves** | | | | | | |
| CV-101-D | PV-D2VV vent to tent | Circle Seal | 28OT-4PP-1 | 1 psig cracking pressure | 1/2" | Teflon Seals |
| CV-01-H | PV-H2VV vent to tent | Circle Seal | 28OT-4PP-1 | 1 psig cracking pressure | 1/2" | Teflon Seals |
| CV-01-N | N2 gas supply check valve | Nupro | CP | 1 psid cracking pressure | 1/4" | |
| CV-02-N | Air supply check valve | Nupro | CP | 1 psid cracking pressure | 1/4" | |
| | | | | | | |
| **Electric Valves** | | | | | | |
| EV-01-He | Fill/Empty valve solenoid, H2 system | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-101-He | Fill/Empty valve solenoid, D2 system | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-D2VV | Vent Valve solenoid | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-D2SUP | D2 Supply valve solenoid | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-D2FILL | D2 Target fill valve solenoid | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-RPVENTD | Rough pump vent valve | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-FPVENTD | Forepump vent valve | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-H2VV | Vent Valve solenoid | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-H2SUP | H2 Supply valve solenoid | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-H2FILL | H2 Target fill valve solenoid | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-RPVENTH | Rough pump vent valve | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-FPVENTH | Forepump vent valve | Skinner | V53DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| EV-WTRDRN | Air compressor water drain | Skinner | V58DB2150, 110 VAC | 150 psid | 1/4" | 3-way, Normally Closed |
| | | | | | | |
| **EXCESS FLOW VALVES** | | | | | | |
| EFV-101-D | D2 Excess flow valve | Nupro | 6L-E4LE-FR4-VR4 | 225 psig | 1/4" | Burst Press. = 12000 psi |
| EFV-01-H | H2 Excess flow valve | Nupro | 6L-E4LE-FR4-VR4 | 225 psig | 1/4" | Burst Press. = 12000 psi |
| | | | | | | |
| **ELECTRO-PNEUMATIC VALVES** | | | | | | |
| EP-D2PURGE | Deuterium circuit purge valve | Skinner | V5D34435, 120VAC | 150 psid | 1 1/8" | 3-way, Normally Closed |
| EP-RUFVLVD | Rough pump shutoff valve | Skinner | V5D34435, 120VAC | 150 psid | 1 1/8" | 3-way, Normally Closed |
| EP-FORVLVD | Forepump shutoff valve | Skinner | V5D34435, 120VAC | 150 psid | 1 1/8" | 3-way, Normally Closed |
| EP-HIVACD | High Vacuum shutoff valve | Vacuumm Research | LP4, 120VAC | Vacuum Valve | 4" | Normally Closed |
| EP-H2PURGE | Hydrogen circuit purge valve | Skinner | V5D34435, 120VAC | 150 psid | 1 1/8" | 3-way, Normally Closed |
| EP-RUFVLVH | Rough pump shutoff valve | Skinner | V5D34435, 120VAC | 150 psid | 1 1/8" | 3-way, Normally Closed |
| EP-FORVLVH | Forepump shutoff valve | Skinner | V5D34435, 120VAC | 150 psid | 1 1/8" | 3-way, Normally Closed |
| EP-HIVACH | High Vacuum shutoff valve | Vacuumm Research | LP4, 120VAC | Vacuum Valve | 4" | Normally Closed |
| | | | | | | |
| **FILTERS** | | | | | | |
| F-01-N | Air compressor filter | PALL | PA212100Av | vendor supplied | 1/4" | |

| MANUAL VALVES | | | | | |
|---|---|---|---|---|---|
| MV-101-D | Post RV-101-D shutoff | Nupro | B-4HK2 | 1000 psig | 1/4" |
| MV-102-D | Pre pump cart shutoff valve | Matheson | 103 | 3000 psig | 1/4" |
| MV-104-D | Cold trap inlet valve | Nupro | 6L-LD8 2293 | 300 psig | 1/2" |
| MV-105-D | Cold trap bypass valve | Nupro | 6L-LD8 2293 | 300 psig | 1/2" |
| MV-106-D | Cold trap outlet valve | Nupro | 6L-LD8 2293 | 300 psig | 1/2" |
| MV-107-D | Cold trap purge valve | Nupro | SS-4BK-VCO | 1000 psig | 1/4" |
| MV-110-D | PT-D2SUP shutoff valve | Nupro | B-4HK2 | 1000 psig | 1/4" |
| MV-111-D | PT-D2SUP pumpout valve | Nupro | B-4HK2 | 1000 psig | 1/4" |
| MV-112-D | PT-D2VENT shutoff valve | Nupro | B-4HK2 | 1000 psig | 1/4" |
| MV-113-D | PT-D2VENT pumpout valve | Nupro | B-4HK2 | 1000 psig | 1/4" |
| MV-01-H | Post RV-01-H shutoff | Nupro | B-4HK2 | 1000 psig | 1/4" |
| MV-02-H | Pre pump cart shutoff valve | Matheson | 103 | 3000 psig | 1/4" |
| MV-04-H | Cold trap inlet valve | Nupro | 6L-LD8 2293 | 300 psig | 1/2" |
| MV-05-H | Cold trap bypass valve | Nupro | 6L-LD8 2293 | 300 psig | 1/2" |
| MV-06-H | Cold trap outlet valve | Nupro | 6L-LD8 2293 | 300 psig | 1/2" |
| MV-07-H | Cold trap purge valve | Nupro | SS-4BK-VCO | 1000 psig | 1/4" |
| MV-10-H | PT-H2SUP shutoff valve | Nupro | B-4HK2 | 1000 psig | 1/4" |
| MV-11-H | PT-H2SUP pumpout valve | Nupro | B-4HK2 | 1000 psig | 1/4" |
| MV-12-H | PT-H2VENT shutoff valve | Nupro | B-4HK2 | 1000 psig | 1/4" |
| MV-13-H | PT-H2VENT pumpout valve | Nupro | B-4HK2 | 1000 psig | 1/4" |
| MV-02-He | Pre pump cart shutoff, H2 system | Hoke | 4151M4B | 600 psig | 1/4" |
| MV-102-He | Pre pump cart shutoff, D2 system | Hoke | 4151M4B | 600 psig | 1/4" |
| MV-03-He | Helium Supply Valve | Hoke | 4151M4B | 601 psig | 1/4" |
| MV-01-N | Post nitrogen regulator shutoff | Linde | NA | 3000 psig | 1/4" |
| MV-02-N | Pre pump cart shutoff valve, H2 system | Hoke | 4151M4B | 600 psig | 1/4" |
| MV-03-N | PT-PN2SUP pumpout valve | Nupro | SS-4PAT4 | 3000 psig | 1/4" |
| MV-04-N | PT-PN2SUP isolation valve | Nupro | SS-4PAT4 | 3000 psig | 1/4" |
| MV-05-N | Filter/dryer isolation valve | Nupro | SS-4PAT4 | 3000 psig | 1/4" |
| MV-06-N | Air compressor drain valve | Nupro | SS-4PAT4 | 3000 psig | 1/4" |
| MV-07-N | Compressor water drain hand valve | Campbell-Hausfield | vendor supplied | NA | 1/4" |
| MV-08-N | Vent Valve pneumatic supply isolation | Nupro | SS-4PAT4 | 3000 psig | 1/4" |
| MV-09-N | Air compressor isolation valve | Nupro | SS-4PAT4 | 3000 psig | 1/4" |
| MV-10-N | Pump cart isolation valve | Nupro | SS-4PAT4 | 3000 psig | 1/4" |
| MV-102-N | Pre pump cart shutoff valve, D2system | Hoke | 4151M4B | 600 psig | 1/4" |
| MV-01-V | Rough line bleed valve, H2 system | Hoke | 4151M4B | 600 psig | 1/4" |
| MV-02-V | Fore pump vent valve, H2 system | Hoke | 4151M4B | 600 psig | 1/4" |
| MV-03-V | Vacuum shutoff to EV-01-He, H2 system | Hoke | 4151M4B | 600 psig | 1/4" |
| MV-101-V | Rough line bleed valve, D2 system | Hoke | 4151M4B | 600 psig | 1/4" |
| MV-102-V | Fore pump vent valve, D2 system | Hoke | 4151M4B | 600 psig | 1/4" |
| MV-103-V | Vacuum shutoff to EV-101-He, D2 system | Hoke | 4151M4B | 600 psig | 1/4" |

| | | | | | | |
|---|---|---|---|---|---|---|
| **PNEUMATIC VALVES** | | | | | | |
| PV-D2SUP | D2 Supply valve to target | Nupro | SS-4BK-NC, Series 1 | 1000 psig | 1/4" | Normally Closed |
| PV-D2FILL | D2 Target Fill Valve | Nupro | SS-4BK-NC, Series 1 | 1000 psig | 1/4" | Normally Closed |
| PV-D2VV | D2 Target Vent Valve | Nupro | SS8UWVCRTFT2-4C | 2500 psig | 1/2" | Normally Closed |
| PV-H2SUP | H2 Supply valve to target | Nupro | SS-4BK-NC, Series 1 | 1000 psig | 1/4" | Normally Closed |
| PV-H2FILL | H2 Target Fill Valve | Nupro | SS-4BK-NC, Series 1 | 1000 psig | 1/4" | Normally Closed |
| PV-H2VV | H2 Target Vent Valve | Nupro | SS8UWVCRTFT2-4C | 2500 psig | 1/2" | Normally Closed |
| | | | | | | |
| **REGULATORS** | | | | | | |
| RV-101-D | Deuterium cylinder regulator | Victor | VTS-452B | 2 to 40 psig | 1/4" | NOP = 10 psig |
| RV-102-D | Pump cart D2 regulator | Air Products | E11-N141A | 0 to 25 psig | 1/4" | NOP = 3 psig |
| RV-01-H | Hydrogen cylinder regulator | Victor | VTS-452B | 2 to 40 psig | 1/4" | NOP = 10 psig |
| RV-02-H | Pump cart H2 regulator | Air Products | E11-N141A | 0 to 25 psig | 1/4" | NOP = 3 psig |
| RV-01-N | Nitrogen cylinder regulator | Linde | UPG 3 150 580 | 0 to 150 psig | 1/4" | NOP = 105 psig |
| RV-02-N | Pneumatic air compressor regulator | Matheson | 3590 | 2 to 100 psig | 1/4" | NOP = 60 psig |
| RV-01-He | Helium cylinder regulator, H2 system | Harris | 93-350A | 0 to 350 psig | 1/4" | |
| RV-02-He | Helium supply regulator, H2 system | Grove | 202G | | 1" | |
| | | | | | | |
| **SAFETY VALVES** | | | | | | |
| SV-101-D | D2 Supply line relief | Nupro | B-8CPA2-3 | 110 psig | 1/2" | |
| SV-102-D | Target D2 supply relief | Nupro | B-8CPA2-3 | 10 psig | 1/2" | |
| SV-103-D | Target D2 vent lilne relief | Anderson-Greenwood | 83MB68-6 | 10 psig | 3/8" orifice | |
| SV-104-D | D2 Cold trap relief valve | Nupro | B-8CPA2-3 | 50 psig | 1/2" | |
| SV-01-H | H2 Supply line relief | Nupro | B-8CPA2-3 | 110 psig | 1/2" | |
| SV-02-H | Target H2 supply relief | Nupro | B-8CPA2-3 | 10 psig | 1/2" | |
| SV-03-H | Target H2 vent line relief | Anderson-Greenwood | 83MB68-6 | 10 psig | 3/8" orifice | |
| SV-04-H | H2 Cold trap relief valve | Nupro | B-8CPA2-3 | 50 psig | 1/2" | |
| SV-01-N | Nitrogen gas supply relief | Circle Seal | 5159B-4MP | 140 psig | 1/2" | |
| SV-02-N | Air compressor relief | Campbell-Hausfield | SP25 | 140 psig | 1/4" | Code Stamped |
| SV-01-V | Refrigirator can relief, H2 system | Fermilab design | parallel plate | lift pressure <= 3.5 psid | 2" | |
| SV-02-V | Target vacuum relief, H2 system | Fermilab design | parallel plate | lift pressure <= 3.5 psid | 2" | |
| SV-101-V | Refrigirator can relief, D2 system | Fermilab design | parallel plate | lift pressure <= 3.5 psid | 2" | |
| SV-102-V | Target vacuum relief, D2 system | Fermilab design | parallel plate | lift pressure <= 3.5 psid | 2" | |
| SV-01-He | Helium gas supply relief, H2 system | Nupro | B-8CPA2-3 | 300 psig | 1/2" | |
| | | | | | | |
| **ANALYZERS** | | | | | | |
| AE-01 | Flammable gas detector | Controls Instruments | B3SNR005 | | | |
| AIS-01 | Detector indication switch | Controls Instruments | | 0 to 100% of LEL | 12VDC | Set Pt = 1% H2 in air = 25% of LEL |
| | | | | | | |
| **FLOW DEVICES** | | | | | | |
| FT-D2SUP | Deuterium gas supply flow | MKS | 0558C-050L-GV-SPCAL-H2 | 0 to 50 slpm H2 | 0 to 5.0 volts | |
| FT-H2SUP | Hydrogen gas supply flow | MKS | 0558C-050L-GV-SPCAL-H2 | 0 to 50 slpm H2 | 0 to 5.0 volts | |
| FE-TENTFAN | Tent fan flow | Annubar | AIR-26 for 10" circ. duct | | | |
| FIS-TENTFAN | Tent fan flow indication | Annubar | EFW | 0 to 1500 actual CFM air | | electronic relay on-off |

| | | | | | |
|---|---|---|---|---|---|
| **HEATERS** | | | | | |
| HTR-101-D | D2 system 2 heater | Minco | H4A20W115 | 0-20 Watts (3 installed) | 0 to 100.0 volts |
| HTR-101-OIL | Diffusion Pump heater, D2 target system | NRC Diffusion Pump | vendor supplied | | Pump Model # 0159 |
| HTR-01-H | H2 system heater | Minco | H4A20W115 | 0-20 Watts (3 installed) | 0 to 100.0 volts |
| HTR-01-OIL | Diffusion Pump heater, H2 target system | NRC Diffusion Pump | vendor supplied | | Pump Model # 0159 |
| | | | | | |
| **POWER TRANSMITTER** | | | | | |
| JT-HTRD | D2 tgt. Variac with Silicon Controlled Rectifier | Watlow | DA10-24F0-0000 | 0 to 100 Watts | 4 to 20 mA |
| JT-HTRH | H2 tgt. Variac with Silicon Controlled Rectifier | Watlow | DA10-24F0-0000 | 0 to 100 Watts | 4 to 20 mA |
| | | | | | |
| **PRESSURE ELEMENTS** | | | | | |
| PE-RPVACD | Rough pump vacuum | Fredericks Televac | 2A | 0 to 1000 micron | 0 to 7 volts |
| PE-FPVACD | Forepump vacuum | Fredericks Televac | 2A | 0 to 1000 micron | 0 to 7 volts |
| PE-INSULVACD | Insulating Vacuum Pressure | Fredericks Televac | 7B | 10-3 to 10-8 Torr | Power supply not installed in rack |
| PE-RPVACH | Rough pump vacuum | Fredericks Televac | 2A | 0 to 1000 micron | 0 to 7 volts |
| PE-FPVACH | Forepump vacuum | Fredericks Televac | 2A | 0 to 1000 micron | 0 to 7 volts |
| PE-INSULVACH | Insulating Vacuum Pressure | Fredericks Televac | 7B | 10-3 to 10-8 Torr | Power supply not installed in rack |
| | | | | | |
| **PRESSURE INDICATORS** | | | | | |
| PI-101-D | PT-D2SUP readout device | FIXDMACS | | | |
| PI-102-D | RV-101-D inlet pressure | US Gauge | | 0 to 4000 psig | |
| PI-103-D | RV-101-D outlet pressure | US Gauge | | 0 to 60 psig | |
| PI-107-D | RV-102-D outlet pressure | Air Products supplied | | neg. 30 in Hg to 30 psig | |
| PI-01-H | PT-H2SUP readout device | FIXDMACS | | | |
| PI-02-H | RV-01-H Inlet pressure | US Gauge | | 0 to 4000 psig | |
| PI-03-H | RV-01-H outlet pressure | US Gauge | | 0 to 60 psig | |
| PI-07-H | RV-02-H outlet pressure | Air Products supplied | | neg. 30 in Hg to 30 psig | |
| PI-01-He | 1" He suction header pressure | FIXDMACS | | | |
| PI-02-He | 1" He discharge header pressure, H2 tgt | FIXDMACS | | | |
| PI-03-He | RV-01-He Inlet pressure, H2 tgt | US Gauge | | 0 to 4000 psig | |
| PI-01-N | RV-01-N inlet pressure | NKS Nagano | | 0 to 4000 psig | |
| PI-02-N | RV-01-N outlet pressure | NKS Nagano | | 0 to 200 psig | |
| PI-04-N | RV-02-N outlet pressure | US Gauge | | 0 to 100 psig | |
| PI-05-N | Air supply pressure at H2 pumpcart | US Gauge | | 0 to 100 psig | |
| PI-06-N | Air compressor supply pressure | US Gauge | | 0 to 200 psig | |
| PI-105-N | Air supply pressure at D2 pumpcart | US Gauge | | 0 to 100 psig | |
| PI-01-V | PT-01-V readout device, H2 tgt | MKS Instruments | PDR-C-2C-BCD | 0 to 10 mmHg | |
| PI-02-V | PT-02-V readout device, H2 tgt | MKS Instruments | PDR-C-2C-BCD | 0 to 1000 mmHg | |
| PI-03-V | Insulating vacuum, H2 tgt | Fredericks Televac | 7B | 10-3 to 10-8 Torr | |
| PI-101-V | PT-01-V readout device, D2 tgt | MKS Instruments | PDR-C-2C-BCD | 0 to 10 mmHg | |
| PI-102-V | PT-02-V readout device, D2 tgt | MKS Instruments | PDR-C-2C-BCD | 0 to 1000 mmHg | |
| PI-103-V | Insulating vacuum, D2 tgt | Fredericks Televac | 7B | 10-3 to 10-8 Torr | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **PRESSURE TRANSMITTERS** | | | | | | |
| PT-D2SUP | Deuterium supply pressure | Setra | 205-2 | 0 to 50 psia | 0 to 5 Volts | |
| PT-D2VENT | Deuterium flask pressure | Setra | 205-2 | 0 to 50 psia | 0 to 5 Volts | |
| PT-H2SUP | Hydrogen supply pressure | Setra | 205-2 | 0 to 50 psia | 0 to 5 Volts | |
| PT-H2VENT | Hydrogen flask pressure | Setra | 205-2 | 0 to 50 psia | 0 to 5 Volts | |
| PT-COMPOISH | 1" He discharge header pressure, H2 tgt | Ashcroft | G2 | 0 to 500 psig | 4 to 20 mA | |
| PT-COMPOISD | 1" He discharge header pressure, D2 tgt | Ashcroft | G2 | 0 to 500 psig | 4 to 20 mA | |
| PT-PN2SUP | Pneumatic supply pressure | Setra | C206 | 0 to 500 psig | 4 to 20 mA | |
| PT-01-V | Insulating Vacuum Pressure, H2 tgt | MKS Instruments | 122AA-00010A | 0 to 10 mmHg | 0 to 10 volts | |
| PT-02-V | Insulating Vacuum Pressure, H2 tgt | MKS Instruments | 122AA-01000AB | 0 to 1000 mmHg | 0 to 10 volts | |
| PT-101-V | Insulating Vacuum Pressure, D2 tgt | MKS Instruments | 122AA-00010A | 0 to 10 mmHg | 0 to 10 volts | |
| PT-102-V | Insulating Vacuum Pressure, D2 tgt | MKS Instruments | 122AA-01000AB | 0 to 1000 mmHg | 0 to 10 volts | |
| | | | | | | |
| **SWITCHES** | | | | | | |
| ISL-FPD | Current switch low | SSAC | ECS41BC | adjustable 2 to 20 Amps | 12 VDC | on D2 system Fore Pump |
| ISL-RPD | Current switch low | SSAC | ECS41BC | adjustable 2 to 20 Amps | 12 VDC | on D2 system Rough Pump |
| ISL-FPH | Current switch low | SSAC | ECS41BC | adjustable 2 to 20 Amps | 12 VDC | on H2 system Fore Pump |
| ISL-RPH | Current switch low | SSAC | ECS41BC | adjustable 2 to 20 Amps | 12 VDC | on H2 system Rough Pump |
| PS-01-N | Air compressor ON-OFF | Condor | MDR 21/11 | 160 psig | | 110/135 psig set pts. |
| | | | | | | |
| **TEMPERATURE ELEMENTS** | | | | | | |
| TE-D2FLUP | Deuterium flask top | Allen-Bradley | | 100 Ohm | | |
| TE-D2FLDWN | Deuterium flask down | Allen-Bradley | | 100 Ohm | | |
| TE-D2CPOT | D2 condenser | Lakeshore | CX-1030-SD cernox | 50 to 700 Ohms (4-300K) | | |
| TE-D2SVEXH | D2 AGCO safety valve exhaust | Lakeshore | PT102 Platinum RTD | 10 to 200 Ohms (14-300K) | | |
| TE-H2FLUP | Hydrogen flask top | Allen-Bradley | | 100 Ohm | | |
| TE-H2FLDWN | Hydrogen flask down | Allen-Bradley | | 100 Ohm | | |
| TE-H2CPOT | H2 condenser | Lakeshore | CX-1030-SD cernox | 50 to 700 Ohms (4-300K) | | |
| TE-H2SVEXH | H2 AGCO safety valve exhaust | Lakeshore | PT102 Platinum RTD | 10 to 200 Ohms (14-300K) | | |
| | | | | | | |
| **TEMPERATURE SWITCHES** | | | | | | |
| TSH-01-W | Temperature switch H compressor | Cryomech | | | | |
| TSD-01-W | Temperature switch D compressor | Cryomech | | | | |

## D. INTERLOCK/ALARM LIST

### Interlocks

1. Hydrogen Insulating vacuum pressure PT-01-V > 0.1 torr or
   foreline pressure PE-FPVACH > 75 microns

    a. EP-HIVACH valve is closed, and roughing valve EP-RUFVLVH is opened. This switches pumping from diffusion pump/forepump system to roughing pump.

    b. Cryocooler shutdown.

    c. Beam will be shutdown.

2. Deuterium Insulating vacuum pressure PT-101-V > 0.1 torr or
   foreline pressure PE-FPVACD > 75 microns

    a. EP-HIVACD valve is closed, and roughing valve EP-RUFVLVD is opened. This switches pumping from diffusion pump/forepump system to roughing pump.

    b. Cryocooler shutdown.

    c. Beam will be shutdown.

3. Hydrogen flask pressure PT-H2VENT > 20 psia or PT-H2SUP> 20 psia

    Hydrogen vent valve, PV-H2VV, is opened. Beam is turned off. Heater is turned off.

4. Deuterium flask pressure PT-D2VENT > 20 psia or PT-D2SUP> 20 psia

    Deuterium vent valve, PV-D2VV, is opened. Beam is turned off. Heater is turned off.

5. PV-H2SUP and EP-H2PURGE will be interlocked such that they cannot be opened at the same time.

6. PV-D2SUP and EP-D2PURGE will be interlocked such that they cannot be opened at the same time.

7. TSH-01-W high

    Factory set temperature switch. Shuts down compressor if the gas outlet temperature is too high.

8. TSD-01-W high

Factory set temperature switch.  Shuts down compressor if the gas outlet temperature is too high.

9. Tent Fan Failure

   FIS-TENTFAN will show no flow during tent fan failure.  Target Table motor will turn off.  Beam will turn off.

## Alarms

1. Hydrogen insulating vacuum pressure HIHI and HI.  PE-FPVACH or PT-01-V will trigger alarm.
2. Deuterium insulating vacuum pressure HIHI and HI.  FPVACD or PT-101-V will trigger alarm.
3. Hydrogen rough pump failure.  PE-RPVACH HI will trigger alarm.
4. Deuterium rough pump failure.  PE-RPVACD HI will trigger alarm.
5. Hydrogen diffusion pump failure.  PE-FPVACH pressure will decrease, while PT-01-V will increase.  PE-FPVACH LO will trigger alarm.  PT-01-V HI will trigger alarm.
6. Deuterium diffusion pump failure.  PE-FPVACD pressure will decrease, while PT-101-V will increase.  PR-FPVACD LO will trigger alarm.  PT-101-V HI will trigger alarm.
7. Hydrogen cryocooler failure.
   a. A decrease in cooling power will show up as a decrease in condenser heater power. Heater power LO will trigger alarm.
   b. Cryocooler compressor failure would result in reduction of He high line pressure PT-HCOMP.  He line pressure PT-HCOMP LO will trigger alarm.
8. Deuterium cryocooler failure.
   a. A decrease in cooling power will show up as a decrease in condenser heater power. Heater power LO will trigger alarm.
   b. Cryocooler compressor failure would result in reduction of He line pressure PT-DCOMP.  He line pressure PT-DCOMP LO will trigger alarm.
9. Hydrogen flask pressure. PT-H2VENT LOLO, LO, HI, and HIHI states will trigger alarm (PT-H2VENT HI also to Main Control to shut off beam)

10. Deuterium flask pressure. PT-D2VENT LOLO, LO, HI, and HIHI states will trigger alarm (PT-D2VENT HI also to Main Control to shut off beam)
11. Hydrogen compressor cooling water flow LOLO, LO, HI, and HIHI and temperature HI and HIHI will trigger alarm.
12. Deuterium compressor cooling water flow LOLO, LO, HI, and HIHI and temperature HI and HIHI will trigger alarm.
13. AC Power failure. Control system will be on UPS. UPS will alarm during power failure.
14. Fan flow. A detector will trigger an alarm if ventilation fan flow falls below the LOLO and LO set value
15. Table motion. Problems with table motion (e.g., encoder not agreeing with steps sent) will trigger an alarm (also to Main Control to shut off beam).
16. Pneumatic gas pressure. PT-PN2SUP LO (air compressor LO) and LOLO (Nitrogen pressure LO) will trigger an alarm.
17. Heater power LOLO, LO, HI, and HIHI will trigger an alarm.
18. Current switch ISLFPH LO and LOLO will trigger an alarm.
19. Current switch ISLFPD LO and LOLO will trigger an alarm.
20. Current switch ISLRPH LO and LOLO will trigger an alarm.
21. Current switch ISLRPD LO and LOLO will trigger an alarm.

# E. OPERATING PROCEDURES

## TARGET INSTALLATION LOG

**E906 – Liquid Hydrogen Target System**

The basic design of the E906 Liquid Hydrogen Target System will be identical to that of the E866 Experiment, with the exception that the E906 cryocooler will not need an external helium source during operation.

| | By | Date | |
|---|---|---|---|
| 1. | ______ | ______ | Target placed into position in beam line. |
| 2. | ______ | ______ | H2 Pump Cart in position. |
| 3. | ______ | ______ | Ground connection to target. |
| 4. | ______ | ______ | Foreline connected to target. |
| 5. | ______ | ______ | H2 supply line connected to target. |
| 6. | ______ | ______ | Roughing line connected to target. |
| 7. | ______ | ______ | Refrigerator gas lines connected and leak checked. |
| 8. | ______ | ______ | Pneumatic lines connected to target. |
| 9. | ______ | ______ | Hydrogen & pneumatic lines connected to pump cart. |
| 10. | ______ | ______ | Pressure transducer cables connected to both transducers, PT-H2SUP and PT-H2VENT. |
| 11. | ______ | ______ | Discharge gauge connected (gauge powered only when hydrogen is not present) |
| 12. | ______ | ______ | Connect target table controller cables to target table. |
| 13. | ______ | ______ | Cryostat instrumentation cables connected to cryostat. |
| 14. | ______ | ______ | Pump cart control cable connected to pump cart. |
| 15. | ______ | ______ | Diffusion pump and high vacuum valve cable connected. |
| 16. | ______ | ______ | 220 Volts 3 phase 60 amp disconnect checked for 15 amp fuses. Replace fuses if they are larger. |
| 17. | ______ | ______ | Plug pump cart into 220 volt receptacle. |
| 18. | ______ | ______ | Plug hydrogen compressor power cable into 220 volt receptacle. |
| 19. | ______ | ______ | Connect pump cart cable to breakout box. |
| 20. | ______ | ______ | Connect PT-01-V gauge cable to breakout box. |
| 21. | ______ | ______ | Connect refrigerator cable to compressor |

package.

22. ______ ______ Connect water hoses to hydrogen compressor package.
23. ______ ______ Cryostat instrumentation cables connected to breakout box.
24. ______ ______ Connect Flammable Gas detector cable to control rack.
25. ______ ______ Tie down all cables and lines, check for interference with target table motion, correct where necessary.
26. ______ ______ Do general housekeeping around target area.
27. ______ ______ Install guards over cables and lines when necessary.
28. ______ ______ Remove guard on target windows when appropriate.
29. ______ ______ Install rotating warning lights in vicinity of target and in pump cart area.
30. ______ ______ Install warning signs at designated locations.
31. ______ ______ Leak test all gas connections with Nitrogen or Helium. Test Hydrogen line with Helium gas. Reconnect Hydrogen when tests are completed. Secure all cylinders and tag properly.

COMMENT :

Initial manual valve status prior to hydrogen target starting procedure.

Open: MV-04-H, MV-06-H, MV-10-H, MV-12-H, MV-14-H, MV-02-He, MV-03-He, MV-01-N, MV-02-N, MV-04-N, MV-05-N, MV-06-N, MV-08-N, MV-09-N, MV-10-N

Closed: MV-01-H, MV-02-H, MV-05-H, MV-07-H, MV-11-H, MV-13-H, MV-03-N, MV-07N, MV-01-V, MV-02-V, MV-03-V

Regulators backed off

Control Console

| | By | Date | |
|---|---|---|---|
| 1. | _______ | _______ | All cables connected to rack. |
| 2. | _______ | _______ | Power on to programmable logic controller. |
| 3. | _______ | _______ | Power on to target control system computer. |
| 4. | _______ | _______ | Power to Flammable Gas Detector. Test alarm whooper and reset. |
| 5. | _______ | _______ | Check housekeeping in area around control console. |
| 6. | _______ | _______ | Check that UPS is operational. |

Cylinders and System Regulators Installation

Note: Keep cylinder valves closed at this time.

| | | | |
|---|---|---|---|
| 1. | _______ | _______ | Nitrogen cylinder installed with RV-01-N for pneumatic air backup. |
| 2. | _______ | _______ | Air compressor installed with RV-02-N for pneumatic air supply. |
| 3. | _______ | _______ | Check compressor helium pressure (200-210 psi). |
| 4. | _______ | _______ | Hydrogen cylinder installed with RV-01-H for liquid hydrogen target purge and fill. |

## LH2 TARGET STARTING/RESTARTING CHECK LIST

Target Area

| | By | Date | |
|---|---|---|---|
| 1. | _______ | _______ | No physical damage to equipment. |
| 2. | _______ | _______ | No Physical damage to lines. |
| 3. | _______ | _______ | No Physical damage to cables. |
| 4. | _______ | _______ | Target windows intact. |
| 5. | _______ | _______ | Vacuum pump oil level normal. |
| 6. | _______ | _______ | All lines connected to target and pump cart. |
| 7. | _______ | _______ | Rotating lights turned on. |
| 8. | _______ | _______ | Disconnects and all circuit breakers on. |
| 9. | _______ | _______ | Nitrogen pressure is OK. |
| 10. | _______ | _______ | Air compressor is operational. |

Note: Steps 11 and 12 should be performed in step 18 of Target Starting Procedure during initial startup of system.

| | | | |
|---|---|---|---|
| 11. | _______ | _______ | Open hydrogen cylinder, set pressure to 5 psig (RV-01-H). Note pressures______ ______. Close cylinder valve. High pressure gauge must show no noticeable drop for 5 minutes. If no leaks are present, reopen cylinder valve. |
| 12. | _______ | _______ | Set RV-02-H to 3 psig (RV-01-H may then be set to 10 psig). Note Pressure ________. |
| 13. | _______ | _______ | Open Nitrogen cylinder, set pressure to 50 psig (RV-01-N). Note pressures______ ______. Close cylinder valve. Test for leakage as above. Reopen cylinder valve if no leaks are present. |
| 14. | _______ | _______ | Start Air Compressor and open MV-05-N. Set pressure to 60 psig (RV-02-N). Note pressure ______. |
| 15. | _______ | _______ | Install covers over cylinders where necessary. |
| 16. | _______ | _______ | Hydrogen detector in place. |
| 17. | _______ | _______ | Housekeeping in area around target is good. |

18. ______ ______ All warning signs in area prominently displayed and unobstructed.

**TARGET STARTING PROCEDURE**

1. ________ Check oil level in vacuum pumps.

2. ________ Note Pneumatic Supply Pressure on pump cart gauge, PI-05-N, ______ psig. Pneumatic system valves should be positioned as follows: MV-01-N, MV-02-N, MV-04-N, MV-05-N, and MV-08-N should be open. MV-03-N and MV-07-N should be closed.

3. ________ Turn on roughing pump. Pressure should reach 20 microns on PE-RPVACH in 2 minutes.

4. ________ Turn on forepump. Pressure should reach 20 microns on PE-FPVACH in 2 minutes.

5. ________ Open fore line valve EP-FORVLVH.

6. ________ Open roughing valve EP-RUFVLVH to target insulating vacuum.

7. ________ Turn on power to diffusion pump.

8. ________ Enable high vacuum valve, EP-HIVACH. The HIVAC valve on/off switch will blink until target insulating vacuum pressure is low enough for it to open. EP-RUFVLVH closes automatically. This occurs at 75 microns.

9. ________ Be sure that MV-04-H, MV-06-H, MV-10-H and MV-12-H are open.

10. ________ Be sure that MV-05-H, MV-07-H, MV-11-H and MV-13-H are closed.

11. ________ Check that the PLC interlock is enabled for the vent valve, PV-H2VV.

12. ________ Open purge valve EP-H2PURGE; open target fill valve PV-H2FILL. Note that the PLC interlocks will not allow PV-H2SUP and EP-H2PURGE to be open at the same time.

13. ________ Secure the target tent and the area around the target. Close access gates if provided. Start controlled access into area.

14. ________ Be sure MV-01-H and MV-02-H are open.

15. ________ Open hydrogen cylinder, set pressure to 5 psig (RV-01-H). Note pressures______ ______. Close cylinder valve. High

pressure gauge must show no noticeable drop for 5 minutes. If no leaks are present, reopen cylinder valve.

16. _______ Set RV-02-H to 3 psig (RV-01-H may then be set to 10 psig). Note Pressure ________.

17. _______ Verify that EFV-01-H is operable.

18. _______ After the hydrogen supply line and cold trap are pumped out to 30 microns, close purge valve, EP-H2PURGE. Open hydrogen supply valve EP-H2SUP (hydrogen fill valve, EP-H2FILL, is already open). Be sure the hydrogen pressure is set to 3 psig with the pressure regulator RV-02-H.

19. _______ Target pressure read on pressure transducer PT-H2VENT should reach approximately 17.5 psia.

20. _______ Close hydrogen supply valve PV-H2SUP. Open purge valve EP-H2PURGE; Wait for PE-RPVACH to reach 30 microns. Pump and purge the circuit three times. End the pump and purge procedure by leaving PV-H2SUP closed and EP-H2PURGE open .

21. _______ Cool down the Hydrogen cold trap with $LN_2$.

22. _______ Turn on hydrogen compressor.

23. _______ Turn on heater and heater control circuit, set to 14.7 psia.

24. _______ Monitor condenser temperature.

25. _______ Monitor progress of the target on the upper and lower resistors, TE-H2FLUP and TE-H2FLDWN.

26. _______ Continue to fill the target with 240 liters of gas at STP after TE-H2FLUP sees liquid.

27. _______ Close the hydrogen supply valve, PV-H2SUP, and the hydrogen fill valve, PV-H2FILL. Close the hydrogen cylinder supply valve and the manual valve, MV-01-H.

28. _______ Gradually adjust the flask pressure to 14.7 psig. Close MV-14-H.

29. _______ Close MV-06-H (MV-05-H is already closed). Remove the cold trap from the liquid nitrogen.

30. _______ Pump out the cold trap by opening EP-H2Purge and PV-H2Fill. Evacuate cold trap until warm.

31. _______ After trap is warm, close EP-H2PURGE, and PV-H2FILL. Open MV-06-H.

## TARGET SHUTDOWN PROCEDURE

1. ________ Turn off the hydrogen system refrigerator.
2. ________ Turn off temperature controller.
3. ________ Confirm that the hydrogen cylinder supply valve is closed.
4. ________ The liquid inside the hydrogen/ target flask is empty when the hydrogen upper and lower resistor temperatures, TE- H2FLUP and TE-H2FLDWN, exceed 23 K.
5. ________ The hydrogen circuit will continue to hold some amount of hydrogen gas unless complete shutdown is required for certain target maintenance.

**For complete target shutdown, do the following:**

6. ________ Hook up a helium cylinder to MV-07-H, check MV-14-H ,MV-05-H open and backfill the hydrogen circuit with helium to 1 psig. Check PT-H2VENT is 15.5 psig.
7. ________ Close PV-H2SUP. Open PV-H2FILL and EP-H2PURGE. Pump out the target hydrogen circuit. The hydrogen gas is vented through the roughing pump.

**NOTE: BACKFILLING OF CIRCUIT <u>MUST</u> OCCUR IN THIS ORDER TO AVOID CRUSHING THE TARGET FLASK.**

8. ________ Close high vacuum valve EP-HIVACH; turn off diffusion pump heater power. Allow 20 minutes for diffusion pump to cool down.
9. ________ Close fore line valve EP-FORVLVH; turn off power to fore pump.
10. ________ Turn off power to roughing pump.
11. ________ Uncap and open roughing line vent valve at pump cart, MV-01-V, to vent the vacuum space to atmosphere.
12. ________ Turn off electric circuits at the pump cart.
13. ________ Close all gas cylinder valves connected to the target system.
14. ________ Disable the Flammable Gas detector as necessary for welding/brazing repairs.

Date ________________________ By ____________________________________

**TARGET RESTART AFTER POWER OUTAGE OCCURS**

1. _______ After power is restored, open hydrogen system roughing valve EP-RUFVLVH and fore valve EP-FORVLVH.
2. _______ Enable high vacuum valve EP-HIVACH. When pressure in the insulating vacuum is low enough (PT-01-V<75 microns), EP-HIVACH will open and EP-RUFVLVH will automatically close.
3. _______ After system analysis by a hydrogen target expert, turn on compressor flow and refrigerator if permitted.
4. _______ Check SV-02-H and SV-03-H have been lifted and resealed.
5. _______ Turn on heater controller and be sure the set pressure is 14.7 psia.
6. _______ Check the hydrogen circuit upper and lower resistors, TE-H2FLUP and TE-H2FLDWN, as some hydrogen may need to be added to the hydrogen circuit.
7. _______ If required, open cylinder and manual valves, open PV-H2SUP and PV H2FILL to add hydrogen. Use the cold trap while adding hydrogen as instructed in the TARGET STARTING PROCEDURE.
8. _______ Close PV-H2FILL and PV-H2SUP.
9. _______ Adjust set pressure to 14.7 psia.

**E906 – Liquid Deuterium Target System**

The basic design of the E906 Liquid Deuterium Target System will be identical to that of the E866 Experiment, with the exception that the E906 cryocooler will not need an external helium source in order to operate the refrigerator.

| | By | Date | |
|---|---|---|---|
| 1. | ______ | ______ | Target placed into position in beam line. |
| 2. | ______ | ______ | D2 Pump Cart in position. |
| 3. | ______ | ______ | Ground connection to target. |
| 4. | ______ | ______ | Foreline connected to target. |
| 5. | ______ | ______ | D2 supply line connected to target. |
| 6. | ______ | ______ | Roughing line connected to target. |
| 7. | ______ | ______ | Refrigerator gas lines connected and leak checked. |
| 8. | ______ | ______ | Pneumatic lines connected to target. |
| 9. | ______ | ______ | Deuterium, & pneumatic lines connected to pump cart. |
| 10. | ______ | ______ | Pressure transducer cable connected to both transducers, PT-D2SUP and PT-D2VENT. |
| 11. | ______ | ______ | Discharge gauge connected (gauge powered only when hydrogen is not present) |
| 12. | ______ | ______ | Connect target table controller cables to target table. |
| 13. | ______ | ______ | Cryostat instrumentation cables connected to cryostat. |
| 14. | ______ | ______ | Pump cart control cable connected to pump cart. |
| 15. | ______ | ______ | Diffusion pump and high vacuum valve cable connected. |
| 16. | ______ | ______ | 220 Volts 3 phase 60 amp disconnect checked for 15 amp fuses. Replace fuses if they are larger. |
| 17. | ______ | ______ | Plug pump cart into 220 volt receptacle. |
| 18. | ______ | ______ | Plug deuterium compressor power cable into 220 volt receptacle. |
| 19. | ______ | ______ | Connect pump cart cable to breakout box. |
| 20. | ______ | ______ | Connect PT-101-V gauge cable to breakout box. |
| 21. | ______ | ______ | Connect refrigerator cable to compressor package. |
| 22. | ______ | ______ | Connect water hoses to hydrogen compressor package. |

23. ______ ______ Cryostat instrumentation cables connected to breakout box.
24. ______ ______ Connect Flammable Gas detector cable to control rack.
25. ______ ______ Tie down all cables and lines, check for interference with manipulators, correct where necessary.
26. ______ ______ Do general housekeeping around target area.
27. ______ ______ Install guards over cables and lines when necessary.
28. ______ ______ Remove guard on target windows when appropriate.
29. ______ ______ Install rotating warning lights in vicinity of target and in pump cart area.
30. ______ ______ Install warning signs at designated locations.
31. ______ ______ Leak test all gas connections with Nitrogen or Helium. Test deuterium line with Helium gas. Reconnect deuterium when tests are completed. Secure all cylinders and tag properly.

COMMENTS:

Initial manual valve status prior to deuterium target starting procedure.

Open: MV-104-D, MV-106-D, MV-110-D, MV-112-D, MV-114-D, MV-02-He, MV-03-He, MV-01-N, MV-02-N, MV-04-N, MV-05-N, MV-06-N, MV-08-N, MV-09-N, MV-10-N

Closed: MV-101-D, MV-102-D, MV-105-D, MV-107-D, MV-111-D, MV-113-D, MV-03-N, MV-07N, MV-101-V, MV-102-V, MV-103-V

Regulators backed off

Control Console

| | By | Date | |
|---|---|---|---|
| 1. | _______ | _______ | All cables connected to rack. |
| 2. | _______ | _______ | Power on to programmable logic controller. |
| 3. | _______ | _______ | Power on to target control system computer. |
| 4. | _______ | _______ | Power to Flammable Gas Detector. Test alarm whooper and reset. |
| 5. | _______ | _______ | Check housekeeping in area around control console. |

Cylinders and System Regulators Installation

Note: Keep cylinder valves closed at this time.

| | | | |
|---|---|---|---|
| 1. | _______ | _______ | Nitrogen cylinder installed with RV-01-N for pneumatic air backup. |
| 2. | _______ | _______ | Air compressor installed with RV-02-N for pneumatic air supply. |
| 3. | _______ | _______ | Check compressor helium pressure (200-210 psi). |
| 4. | _______ | _______ | Deuterium cylinder installed with RV-01-H for liquid deuterium target purge and fill. |

# LD2 TARGET STARTING/RESTARTING CHECK LIST

Target Area

By Date

1. _______ _______ No physical damage to equipment.
2. _______ _______ No physical damage to lines.
3. _______ _______ No physical damage to cables.
4. _______ _______ Target windows intact.
5. _______ _______ Vacuum pump oil level normal.
6. _______ _______ All lines connected to target and pump cart.
7. _______ _______ Rotating lights turned on.
8. _______ _______ Disconnects and all circuit breakers on.
9. _______ _______ Nitrogen pressure is OK.
10. _______ _______ Air compressor is operational.

Note: Steps 11 and 12 should be performed in step 18 of Target Starting Procedure during initial startup of system.

11. _______ _______ Open Deuterium cylinder, set pressure to 5 psig (RV-101-D). Note pressures_______ _______ . Close cylinder valve. High pressure gauge must show no noticeable drop for 5 minutes. If no leaks are present, reopen cylinder valve.

12. . _______ _______ Set RV-102-D to 3 psig (RV-101-D may then be set to 10 psig). Note Pressure _________

13. . _______ _______ Open Nitrogen cylinder, set pressure to 50 psig (RV-01-N). Note pressures_______ _______ Close cylinder valve. Test for leakage as above. Reopen cylinder valve if no leaks are present.

14. . _______ _______ Start Air Compressor and open MV-05-N. Set pressure to 60 psig (RV-02-N). Note pressure _______

15. . _______ _______ Open MV-13-He and set RV-04-He to 3 psig. Note pressure _______

16. . _______ _______ Install covers over cylinders where necessary.

17. . ______ ______ Flammable Gas Detector in place.

18. . ______ ______ Housekeeping in area around target is good.

19. . ______ ______ All warning signs in area prominently displayed and unobstructed.

## TARGET STARTING PROCEDURE

1. ________ Check oil levels in vacuum pumps.

2. ________ Note Pneumatic Supply Pressure on pump cart gauge, PI-105-N, ______ psig. Pneumatic system valves should be positioned as follows: MV-01-N, MV-102-N, MV-04-N, MV-05-N, MV-108-N should be open. MV-03-N and MV-07-N should be closed.

3. ________ Turn on roughing pump. Pressure should reach 20 microns on PE-RPVACD in 2 minutes.

4. ________ Turn on forepump. Pressure should reach 20 microns on PE-FPVACD in 2 minutes.

5. ________ Open fore line valves EP-FORVLVD.

6. ________ Open roughing valve EP-RUFVLVD to target insulating vacuum.

7. ________ Turn on power to diffusion pump.

8. ________ Enable high vacuum valve, EP-HIVACD. The HIVAC valve on/off switch will blink until target insulating vacuum pressure is low enough for it to open. EP-RUFVLVH closes automatically. This occurs at 75 microns.

9. ________ Be sure that MV-104-D, MV-106-D, MV-110-D and MV-112-D are open.

10. ________ Be sure that MV-105-D, MV-107-D, MV-111-D and MV-113-D are closed.

11. ________ Check that the PLC interlock is enabled for the vent valve, PV-D2VV.

12. ________ Open purge valve EP-D2PURGE; open target fill valve PV-D2FILL. Note that the PLC interlocks will not allow PV-D2SUP and EP-D2PURGE to be open at the same time.

13. _________ Secure the target tent and the area around the target. Close access gates if provided. Start controlled access into area.

14. ________ Be sure MV-101-D and MV-102-D are open.

15. ________ Open Deuterium cylinder, set pressure to 5 psig (RV-101-D). Note pressures______ ______ . Close cylinder valve. High pressure

gauge must show no noticeable drop for 5 minutes. If no leaks are present, reopen cylinder valve.

16. ______ Set RV-102-D to 3 psig (RV-101-D may then be set to 10 psig). Note Pressure ________.

17. _______ Verify that EFV-101-D is operable.

18. _______ After the deuterium supply line and cold trap are pumped out to 30 microns, close purge valve, EP-D2PURGE. Open hydrogen suppy valve EP-D2SUP (hydrogen fill valve, EP-D2FILL, is already open). Be sure the deuterium pressure is set to 3 psig with the pressure regulator RV-102-D.

19. _______ Target pressure read on pressure transducer PT-D2VENT should reach approximately 17.5 psia.

20. _______ Close hydrogen supply valve PV-D2SUP. Open purge valve EP-D2PURGE; Wait for PE-RPVACD to reach 30 microns. Pump and purge the circuit three times. End the pump and purge procedure by leaving PV-D2SUP closed and EP-D2PURGE open.

21. _______ Cool down the Deuterium cold trap with $LN_2$.

22. _______ Turn on deuterium compressor.

23. _______ Turn on heater and heater control circuit, set to 14.7 psia.

24. _______ Monitor condenser temperature.

25. _______ Monitor progress of the target on the upper and lower resistors, TE-D2FLUP and TE-D2FLDWN.

26. _______ Continue to fill the target with 240 liters of gas at STP after TE-D2FLUP sees liquid.

27. _______ Close the deuterium supply valve, PV-D2SUP, and the deuterium fill valve, PV-D2FILL. Close the deuterium cylinder supply valve and manual valve, MV-101-D.

28. _______ Turn on heater and heater control circuit to reach 14.7 psig.

29. _______ Gradually adjust the flask pressure to 14.7 psig. Close MV-114-D.

30. _______ Close MV-106-D (MV-105-D is already closed). Remove the cold trap from the liquid nitrogen.

31. _______ Pump out the cold trap by opening EP-D2Purge and PV-D2Fill. Evacuate cold trap until warm.

32. _______ After trap is warm, close EP-D2PURGE, and PV-D2FILL. Open MV-106-D.

# TARGET SHUTDOWN PROCEDURE

1. _______ Turn off the deuterium system refrigerator.
2. _______ Turn off temperature controller.
3. _______ Confirm that the deuterium cylinder supply valve is closed.
4. _______ The liquid inside the deuterium target flask is empty when the deuterium upper and lower resistor temperatures, TE-D2FLUP and TE-D2FLDWN, exceed 23 K.
5. _______ The deuterium circuit will continue to hold some amount of deuterium gas unless complete shutdown is required for certain target maintenance.

**For complete target shutdown, do the following:**

6. _______ Hook up a helium cylinder to MV-107-D, check MV-114-D,MV-05-D are open and backfill the deuterium circuit with helium to 1 psig. Check PT D2VENT is 15.5 psig.
7. _______ Close PV-D2SUP. Open PV-D2FILL and EP-D2PURGE. Pump out the target deuterium circuit. The deuterium gas is vented through the roughing pump.

**NOTE: BACKFILLING OF CIRCUIT <u>MUST</u> OCCUR IN THIS ORDER TO AVOID CRUSHING THETARGET FLASK.**

8. _______ Close high vacuum valve EP-HIVACD; turn off diffusion pump heater power. Allow 20 minutes for diffusion pump to cool down.
9. _______ Close fore line valve EP-FORVLVD; turn off power to fore pump.
10. _______ Turn off power to roughing pump.
11. _______ Uncap and open roughing line vent valve at pump cart, MV-101-V, to vent the vacuum space to atmosphere.
12. _______ Turn off electric circuits at the pump cart.
13. _______ Close all gas cylinder valves connected to the target system.
14. _______ Disable the Flammable Gas detector as necessary for welding/brazing repairs.

Date _________________________ By ______________________________________

## TARGET RESTART AFTER POWER OUTAGE OCCURS

1. _______ After power is restored, open deuterium system roughing valve EP-RUFVLVD and fore valve EP-FORVLVD.

2. _______ Enable high vacuum valve EP-HIVACD. When pressure in the insulating vacuum is low enough (PT-101-V<75 microns), EP-HIVACD will open and EP-RUFVLVD will automatically close.

3. _______ After system analysis by a deuterium target expert, turn on deuterium compressor if permitted.

4. _______ Check SV-102-D and SV-103-D have been lifted and resealed.

5. _______ Turn on the heater controller and be sure the set pressure is 14.7 psia.

6. _______ Check the deuterium circuit upper and lower resistors, TE-D2FLUP and TE-D2FLDWN, as some deuterium may need to be added to the deuterium circuit.

7. _______ If required, open cylinder and manual valves, open PV-D2SUP and PV-D2FILL to add deuterium. Use the cold trap while adding deuterium as instructed in the TARGET STARTING PROCEDURE.

8. _______ Close PV-D2FILL and PV-D2SUP.

9. _______ Adjust set pressure to 14.7 psia.

## F. EMERGENCY PROCEDURES

The emergency procedures for both of the liquid target systems are included below. This is acceptable since the systems are identical. Valves associated with the hydrogen system are identified with an H in the tagname. Those associated with the deuterium system are identified with a D in the tagname. That is, EP-HIVACH is the HIVAC valve in the hydrogen system and EP-HIVACD is the HIVAC valve in the deuterium system. Furthermore, the tagnames identified numerically are distinguished as follows: Tags number 0 through 99 are part of the hydrogen system and tags 100 and greater are part of the deuterium system. The only exceptions are some nitrogen and helium valves which are shared by both systems (see P&I Diagrams to confirm valve/instrument function).

### 1. LOSS OF AC POWER

Indications:

- All equipment shuts down.
- Controls continue working with Uninterruptible Power Supply.

a. All vacuum valves close. Vacuum pumps stop. Compressors and refrigerators stop. Insulating vacuum starts to spoil.

b. Depending on the amount of time the power is off, hydrogen and deuterium will vaporize. Hydrogen and deuterium will be vented through safety valves. No operator action needs to be taken to ensure the safety of the target. No one is allowed inside the tent while power is off.

c. The UPS will continue to keep the control system alive for 2.9 hours after power outage, which will allow the PLC to open pressure valves PV-H2VV/PV-D2VV in order to allow the venting of hydrogen and deuterium through CV-01-H/CV-101-D. In the event that the control system shuts down and the above pressure valves are not opened, the gas will be vented through safety valves SV-03-H/SV-103-D.

d. When power returns, the vacuum system will try to automatically restore the insulating vacuum for the target. The ventilation fan will resume running.

e. If the power has been off for only a few minutes, the compressors and refrigerators may be restarted to restore the targets to full operation. A small loss of hydrogen/deuterium will not affect the operation of the targets.

f. A longer power outage will mean a larger loss of hydrogen/deuterium from the targets. It will be necessary to refill them after refrigerators are restarted. The amount of hydrogen/deuterium to add may be estimated by looking at the temperatures of the upper and lower resistors in each target; TE-H2FLUP, TE-H2FLDWN, TE-D2FLUP and TE-D2FLDWN. See **TARGET RESTART AFTER POWER OUTAGE OCCURS** section.

g. Compressors and the heater power supply will be restarted through operator control.

h. The target motion controller will be restarted through operator control once the hydrogen/deuterium flasks are filled.

## 2. HYDROGEN/DEUTERIUM LEAK

Indications:

- Increase in insulating vacuum pressure.
- Hydrogen reading on the flammable gas detector.

a. A flammable gas alarm is sent to FIXDMACS. The O.D. operators are notified of FIXDMACS alarms. The alarm is also sent to FIRUS. An alarm on the flammable gas detector alone will not require the fire department to respond. However, if coupled with a spoiled insulating vacuum pressure, the fire department will respond to assess the situation. No one is allowed inside the target tent while the flammable gas detector is in alarm.
b. The target is inside a tent. The tent is vented into the hall through a large fan. The fan is continuously running. See Section K for tent design.
c. In any situation where a hydrogen leak has occurred, the entire system must be rechecked for system integrity before restarting the target. One should not confuse venting of a target through its vent valve or relief valve with a leak in the system.

**3. LOSS OF AIR/NITROGEN FOR VALVES**

Indications:

- PT-PN2SUP goes into alarm.
- Eventually pneumatic valves will cease to respond.
- Eventually insulating vacuum spoils.

a. Change nitrogen cylinder if needed. Re-establish vacuum system if needed.
b. Check for leaks.
c. Perform required maintenance to air compressor system.
d. Check target operation indicators. Hydrogen/Deuterium may need to be added. Refill as necessary.
e. Loss of air/nitrogen does not cause a safety problem, but will prevent operation of all pneumatic valves.

**4. LOSS OF REFRIGERATION**

Indications:

- Heater power demand decreases, and heater power alarm trips.
- Target pressures start to rise.

a. Check for vacuum problems.
b. After the target with the poor refrigeration has been shut down and emptied, repairs to that refrigerator may be performed while the other target is full, provided a written procedure is provided to the safety panel and is approved by them, prior to performing the work.
c. Each liquid target (hydrogen and deuterium) has its own cryocooler and compressor. Loss of refrigeration on one may cause that target to warm up and vent through its valve, but would not cause a loss of refrigeration on the other.

**5. LOSS OF THE VENT FAN FROM THE TARGET ENCLOSURE**

Indications:

- Alarm on FIS-TENTFAN
- Power Outage

a. Beam is turned off.

b. Check fan for operation.

c. If the vent fan or sensor for the SeaQuest hall has failed, the fan should be replaced. Spares are available.

d. Target table motor is turned off.

# G. FAILURE MODE AND EFFECTS ANALYSIS

| | | | | |
|---|---|---|---|---|
| PV-H2VV | Closed | Target pressure may increase to SV-03-H setpoint | Safe | SV-03-H would relieve any excess pressure |
| | | | | |
| **REGULATORS** | | | | |
| RV-101-D | Open | Normal operating position | Safe | |
| RV-101-D | Closed | Target would not get D2 for fill | Safe | |
| RV-102-D | Open | Normal operating position | Safe | |
| RV-102-D | Closed | Target would not get D2 for fill | Safe | |
| RV-01-H | Open | Normal operating position | Safe | |
| RV-01-H | Closed | Target would not get H2 for fill | Safe | |
| RV-02-H | Open | Normal operating position | Safe | |
| RV-02-H | Closed | Target would not get H2 for fill | Safe | |
| RV-01-N | Open | Normal operating position | Safe | |
| RV-01-N | Closed | Backup N2 gas supply is isolated | Safe | Air compressor supplies the pneumatic valves |
| RV-02-N | Open | Normal operating position | Safe | |
| RV-02-N | Closed | Pneumatic air supply is isolated | Safe | Backup N2 gas cylinder supplies the pneumatic valves |
| | | | | |
| **SAFETY VALVES** | | | | |
| SV-101-D | Open | Deuterium is vented from supply | Safe | D2 vents into tent; Flammable gas detector triggers tent exhaust fan; D2 is vented through ducting to the outdoors |
| SV-101-D | Closed | Normal operating position | Safe | |
| SV-102-D | Open | Deuterium is vented from supply line | Safe | D2 vents into tent; Flammable gas detector triggers tent exhaust fan; D2 is vented through ducting to the outdoors |
| SV-102-D | Closed | Normal operating position | Safe | |
| SV-103-D | Open | Deuterium is vented from target through the vent line | Safe | |
| SV-103-D | Closed | Normal operating position | Safe | |
| SV-104-D | Open | Deuterium is vented from cold trap | Safe | Would typically only operate when the cold trap is isolated |
| SV-104-D | Closed | Normal operating position | Safe | |
| SV-01-H | Open | Hydrogen is vented from supply | Safe | H2 vents into tent; Flammable gas detector triggers tent exhaust fan; H2 is vented through ducting to the outdoors |
| SV-01-H | Closed | Normal operating position | Safe | |
| SV-02-H | Open | Hydrogen is vented from supply line | Safe | H2 vents into tent; Flammable gas detector triggers tent exhaust fan; H2 is vented through ducting to the outdoors |
| SV-02-H | Closed | Normal operating position | Safe | |
| SV-03-H | Open | Hydogen is vented from target through the vent line | Safe | |
| SV-03-H | Closed | Normal operating position | Safe | |
| SV-04-H | Open | Hydrogen is vented from cold trap | Safe | Would typically only operate when the cold trap is isolated |
| SV-04-H | Closed | Normal operating position | Safe | |
| SV-01-N | Open | Pneumatic backup N2 gas supply is vented | Safe | Air compressor supplies pneumatic valves |
| SV-01-N | Closed | Normal operating position | Safe | |
| SV-02-N | Open | Pneumatic air is vented | Safe | N2 pneumatic supply will continue to pressurize pneumatic lines |
| SV-02-N | Closed | Normal operating position | Safe | |
| SV-01-V | Open | Vacuum would not be achieved | Safe | Operational problem |
| SV-01-V | Closed | Normal operating position | Safe | |
| SV-02-V | Open | Vacuum would not be achieved | Safe | Operational problem |
| SV-02-V | Closed | Normal operating position | Safe | |
| SV-101-V | Open | Vacuum would not be achieved | Safe | Operational problem |
| SV-101-V | Closed | Normal operating position | Safe | |
| SV-102-V | Open | Vacuum would not be achieved | Safe | Operational problem |
| SV-102-V | Closed | Normal operating position | Safe | |

| | | | | |
|---|---|---|---|---|
| **ELECTRO-PNEUMATIC VALVES** | | | | |
| EP-D2PURGE | Open | Rough pump would pump on D2 tubing | Safe | Since during normal operation, PV-D2FILL and PV-D2SUP are closed, there would be little effect. Used in clean-up of system during start-up |
| EP-D2PURGE | Closed | Normal operating position | Safe | |
| EP-RUFVLVD | Open | Rough pump evacuates target vacuum jacket | Safe | Normal during vacuum jacket pump down |
| EP-RUFVLVD | Closed | Normal operating position | Safe | Rough pump is isolated after rough vacuum has been achieved in the target |
| EP-FORVLVD | Open | Normal operating position | Safe | Fore pump pumps on diffusion pump outlet |
| EP-FORVLVD | Closed | Forepump wouldn't pump on diffusion pump, diffusion pump would not operate | Safe | Fore/High Vacuum system will not pump on target insulating vacuum |
| EP-HIVACD | Open | Normal operating position | Safe | Diffusion pump maintains high vacuum in target vacuum jacket |
| EP-HIVACD | Closed | Diffusion pump can not pump on target vacuum jacket | Safe | High vacuum won't be achieved |
| EP-H2PURGE | Open | Rough pump would pump on H2 tubing | Safe | Since during normal operation, PV-H2FILL and PV-H2SUP are closed, there would be little effect. Used in clean-up of system during start-up |
| EP-H2PURGE | Closed | Normal operating position | Safe | |
| EP-RUFVLVH | Open | Rough pump evacuates target vacuum jacket | Safe | Normal during vacuum jacket pump down |
| EP-RUFVLVH | Closed | Normal operating position | Safe | Rough pump is isolated after rough vacuum has been achieved in the target |
| EP-FORVLVH | Open | Normal operating position | Safe | Fore pump pumps on diffusion pump outlet |
| EP-FORVLVH | Closed | Forepump wouldn't pump on diffusion pump, diffusion pump would not operate | Safe | Fore/High Vacuum system will not pump on target insulating vacuum |
| EP-HIVACH | Open | Normal operating position | Safe | Diffusion pump maintains high vacuum in target vacuum jacket |
| EP-HIVACH | Closed | Diffusion pump can not pump on target vacuum jacket | Safe | High vacuum won't be achieved |
| | | | | |
| **FILTERS** | | | | |
| F-01-N | Plugged | Air is not supplied to pneumatic valves from the air compressor | Safe | Nitrogen gas from backup cylinder provides pressure to valves |
| | | | | |
| **MANUAL VALVES** | | | | |
| MV-101-D | Open | Normal operating position during target fill | Safe | |
| MV-101-D | Closed | D2 cylinder not supplying gas for target fill | Safe | |
| MV-102-D | Open | Normal during fill | Safe | |
| MV-102-D | Closed | No D2 supplied to target | Safe | |
| MV-104-D | Open | Normal operating position | Safe | Used during target fill |
| MV-104-D | Closed | D2 would not enter adsorber | Safe | |
| MV-105-D | Open | Contaminated D2 would enter target | Safe | Frozen N2, O2 or H2O may reduce D2 flow into refrigerator or foul the condenser plate, increasing cooldown time |
| MV-105-D | Closed | Normal operating position | Safe | |
| MV-106-D | Open | Normal operating position | Safe | Used during target fill |
| MV-106-D | Closed | D2 would not exit adsorber | Safe | |
| MV-107-D | Open | D2 would vent, target would not fill | Safe | Functions as pumpout port for adsorber regeneration |
| MV-107-D | Closed | Normal operating position | Safe | |
| MV-110-D | Open | Normal operating position | Safe | |
| MV-110-D | Closed | PT-D2SUP would measure incorrect pressure | Safe | Compare to PT-D2VENT reading |
| MV-111-D | Open | Target D2 would vent, target would not fill | Safe | Close MV-110-D |
| MV-111-D | Closed | Normal operating position | Safe | |
| MV-112-D | Open | Normal operating position | Safe | |
| MV-112-D | Closed | PT-D2VENT would measure incorrect pressure, target control is inaccurate | Safe | SV-103-D protects target from overpressures |
| MV-113-D | Open | Target D2 would vent | Safe | Close MV-112-D |
| MV-113-D | Closed | Normal operating position | Safe | |

| | | | | |
|---|---|---|---|---|
| MV-01-H | Open | Normal operating position during target fill | Safe | |
| MV-01-H | Closed | H2 cylinder not supplying gas for target fill | Safe | |
| MV-02-H | Open | Normal during fill | Safe | |
| MV-02-H | Closed | No H2 supplied to target | Safe | |
| MV-04-H | Open | Normal operating position | Safe | Used during target fill |
| MV-04-H | Closed | H2 would not enter adsorber | Safe | |
| MV-05-H | Open | Contaminated H2 would enter target | Safe | Frozen N2, O2 or H2O may reduce D2 flow into refrigerator or foul the condenser plate, increasing cooldown time |
| MV-05-H | Closed | Normal operating position | Safe | |
| MV-06-H | Open | Normal operating position | Safe | Used during target fill |
| MV-06-H | Closed | H2 would not exit adsorber | Safe | |
| MV-07-H | Open | H2 would vent, target would not fill | Safe | Functions as pumpout port for adsorber regeneration |
| MV-07-H | Closed | Normal operating position | Safe | |
| MV-10-H | Open | Normal operating position | Safe | |
| MV-10-H | Closed | PT-H2SUP would measure incorrect pressure | Safe | Compare to PT-H2VENT reading |
| MV-11-H | Open | Target H2 would vent, target would not fill | Safe | Close MV-10-H |
| MV-11-H | Closed | Normal operating position | Safe | |
| MV-12-H | Open | Normal operating position | Safe | |
| MV-12-H | Closed | PT-H2VENT would measure incorrect pressure, target control is inaccurate | Safe | SV-03-H protects target from overpressure |
| MV-13-H | Open | Target H2 would vent | Safe | Close MV-12-H |
| MV-13-H | Closed | Normal operating position | Safe | |
| MV-02-He | Open | Redundant equipment, EV-01-He and MV-03-V are closed | Safe | Normally not used |
| | Closed | Normal operating position | Safe | |
| MV-102-He | Open | Redundant equipment, EV-101-He and MV-103-V are closed | Safe | Normally not used |
| | Closed | Normal operating position | Safe | |
| MV-01-N | Open | Normal operating position | Safe | |
| MV-01-N | Closed | Backup pneumatic N2 gas supply is isolated | Safe | Air compressor supplies gas to pneumatic valves |
| MV-02-N | Open | Normal operating position | Safe | |
| MV-02-N | Closed | Pneumatic air valves would close, stopping H2 flow and vacuum pumping | Safe | Loss of pumping on insulating vacuum, H2 flow would stop during fill |
| MV-03-N | Open | Pneumatic air supply is vented to atmosphere | Safe | Loss of pumping on insulating vacuum, H2/D2 flow would stop during fill |
| MV-03-N | Closed | Normal operating position | Safe | |
| MV-04-N | Open | Normal operating position | Safe | |
| MV-04-N | Closed | PT-PN2SUP would no longer function | Safe | Low Air/Nitrogen pressure alarms will not function |
| MV-05-N | Open | Normal operating position | Safe | |
| MV-05-N | Closed | Air compressor supply to pneumatic valves is isolated | Safe | Nitrogen gas cylinder supplies gas to pneumatic valves |
| MV-07-N | Open | Pressurized air is vent from compressor storage tank | Safe | May have a loss of pumping on insulating vacuum and H2/D2 flow may stop if in fill mode |
| MV-07-N | Closed | Normal operating position | Safe | |
| MV-08-N | Open | Normal operating position | Safe | |
| MV-08-N | Closed | Primary vent valves non-functional | Safe | Backup safety valve will prevent overpressure |
| MV-102-N | Open | Normal operating position | Safe | |
| MV-102-N | Closed | Pneumatic air valves would close, stopping H2 flow and vacuum pumping | Safe | Loss of pumping on insulating vacuum, D2 flow would stop during fill |

| | | | | |
|---|---|---|---|---|
| MV-01-V | Open | If cap is removed, air would enter vacuum jacket | Safe | Vacuum would be lost, H2 will vent |
| MV-01-V | Closed | Normal operating position | Safe | Normally not used |
| MV-02-V | Open | If cap is removed, air would enter vacuum jacket and enter between fore and diffusion pump | Safe | Normally not used, EP-HIVACH closes and EP-RUFVLVH opens |
| MV-02-V | Closed | Normal operating position | Safe | |
| MV-03-V | Open | Redundant equipment, EV-01-He and MV-02-He are closed | Safe | Normally not used |
| MV-03-V | Closed | Normal operating position | Safe | |
| MV-101-V | Open | If cap is removed, air would enter vacuum jacket | Safe | Normally not used |
| MV-101-V | Closed | Normal operating position | Safe | |
| MV-102-V | Open | If cap is removed, air would enter vacuum jacket and enter between fore and diffusion pump | Safe | Normally not used, EP-HIVACD closes and EP-RUFVLVD opens |
| MV-102-V | Closed | Normal operating position | Safe | |
| MV-103-V | Open | Redundant equipment, EV-101-He and MV-102-He are closed | Safe | Normally not used |
| MV-103-V | Closed | Normal operating position | Safe | |
| | | | | |
| **PNEUMATIC VALVES** | | | | |
| PV-D2SUP | Open | Normal during fill, redundant equipment during operation | Safe | All D2 sources are closed during operation |
| PV-D2SUP | Closed | Normal operating position | Safe | |
| PV-D2FILL | Open | Normal during fill and Target pump down, redundant during operation | Safe | All D2 sources are closed during operation |
| PV-D2FILL | Closed | Normal operating position | Safe | |
| PV-D2VV | Open | Target D2 may vent | Safe | CV-101-D may prevent D2 from venting since D2 pressure is not much greater than atmospheric pressure |
| PV-D2VV | Closed | Target pressure may increase to SV-103-D setpoint | Safe | SV-103-D would relieve any excess pressure |
| PV-H2SUP | Open | Normal during fill, redundant equipment during operation | Safe | All H2 sources are closed during operation |
| PV-H2SUP | Closed | Normal operating position | Safe | |
| PV-H2FILL | Open | Normal during fill land Target pump down, redundant during operation | Safe | All H2 sources are closed during operation |
| PV-H2FILL | Closed | Normal operating position | Safe | |
| PV-H2VV | Open | Target H2 may vent | Safe | CV-101-H may prevent H2 from venting since H2 pressure is not much greater than atmospheric pressure |
| PV-H2VV | Closed | Target pressure may increase to SV-03-H setpoint | Safe | SV-03-H would relieve any excess pressure |
| | | | | |
| **REGULATORS** | | | | |
| RV-101-D | Open | Normal operating position | Safe | |
| RV-101-D | Closed | Target would not get D2 for fill | Safe | |
| RV-102-D | Open | Normal operating position | Safe | |
| RV-102-D | Closed | Target would not get D2 for fill | Safe | |
| RV-01-H | Open | Normal operating position | Safe | |
| RV-01-H | Closed | Target would not get H2 for fill | Safe | |
| RV-02-H | Open | Normal operating position | Safe | |
| RV-02-H | Closed | Target would not get H2 for fill | Safe | |
| RV-01-N | Open | Normal operating position | Safe | |
| RV-01-N | Closed | Backup N2 gas supply is isolated | Safe | Air compressor supplies the pneumatic valves |
| RV-02-N | Open | Normal operating position | Safe | |
| RV-02-N | Closed | Pneumatic air supply is isolated | Safe | Backup N2 gas cylinder supplies the pneumatic valves |

| SAFETY VALVES | | | | |
|---|---|---|---|---|
| SV-101-D | Open | Deuterium is vented from supply | Safe | D2 vents into tent; Flammable gas detector triggers tent exhaust fan; D2 is vented through ducting to the outdoors |
| SV-101-D | Closed | Normal operating position | Safe | |
| SV-102-D | Open | Deuterium is vented from supply line | Safe | D2 vents into tent; Flammable gas detector triggers tent exhaust fan; D2 is vented through ducting to the outdoors |
| SV-102-D | Closed | Normal operating position | Safe | |
| SV-103-D | Open | Deuterium is vented from target through the vent line | Safe | |
| SV-103-D | Closed | Normal operating position | Safe | |
| SV-104-D | Open | Deuterium is vented from cold trap | Safe | Would typically only operate when the cold trap is isolated |
| SV-104-D | Closed | Normal operating position | Safe | |
| SV-01-H | Open | Hydrogen is vented from supply | Safe | H2 vents into tent; Flammable gas detector triggers tent exhaust fan; H2 is vented through ducting to the outdoors |
| SV-01-H | Closed | Normal operating position | Safe | |
| SV-02-H | Open | Hydrogen is vented from supply line | Safe | H2 vents into tent; Flammable gas detector triggers tent exhaust fan; H2 is vented through ducting to the outdoors |
| SV-02-H | Closed | Normal operating position | Safe | |
| SV-03-H | Open | Hydogen is vented from target through the vent line | Safe | |
| SV-03-H | Closed | Normal operating position | Safe | |
| SV-04-H | Open | Hydrogen is vented from cold trap | Safe | Would typically only operate when the cold trap is isolated |
| SV-04-H | Closed | Normal operating position | Safe | |
| SV-01-N | Open | Pneumatic backup N2 gas supply is vented | Safe | Air compressor supplies pneumatic valves |
| SV-01-N | Closed | Normal operating position | Safe | |
| SV-02-N | Open | Pneumatic air is vented | Safe | N2 pneumatic supply will continue to pressurize pneumatic lines |
| SV-02-N | Closed | Normal operating position | Safe | |
| SV-01-V | Open | Vacuum would not be achieved | Safe | Operational problem |
| SV-01-V | Closed | Normal operating position | Safe | |
| SV-02-V | Open | Vacuum would not be achieved | Safe | Operational problem |
| SV-02-V | Closed | Normal operating position | Safe | |
| SV-101-V | Open | Vacuum would not be achieved | Safe | Operational problem |
| SV-101-V | Closed | Normal operating position | Safe | |
| SV-102-V | Open | Vacuum would not be achieved | Safe | Operational problem |
| SV-102-V | Closed | Normal operating position | Safe | |

## H. WHAT-IF ANALYSIS

The what-if analysis for both of the liquid target systems is included below. This is acceptable since the systems are identical. Valves associated with the hydrogen system are identified with an H in the tagname. Those associated with the deuterium system are identified with a D in the tagname. That is, EP-HIVACH is the HIVAC valve in the hydrogen system and EP-HIVACD is the HIVAC valve in the deuterium system. Furthermore, the tagnames identified numerically are distinguished as follows: Tags number 0 through 99 are part of the hydrogen system and tags 100 and greater are part of the deuterium system. The only exceptions are some nitrogen and helium valves which are shared by both systems (see Section C).

### (1) Loss of Insulating Vacuum

Initiation:

a. Forepump failure.
b. Foreline hose rupture.
c. Roughing line hose rupture.
d. Diffusion pump failure.
e. Vacuum leak in system.

Automatic Responses:

a. EP-HIVACH/EP-HIVACD closes, and roughing valve EP-RUFVLVH is opened. This switches pumping from diffusion pump/forepump system to roughing pump.
b. The heater will be shutdown via PLC.

Results of Failure:

a. Refrigerator remains on, supplying cooling to target.
b. Refrigeration will not be able to keep the target cool because of the condensing air heat load. At a pressure of 20 psia, the hydrogen vent valve, PV-H2VV/PV-D2VV, will open. If PV-H2VV/PV-D2VV were to fail, SV-02-H/SV-102-D and SV-03-H/SV-103-D will open at a pressure of 10 psig to relieve the hydrogen/deuterium flask.
c. Tent exhaust fan operates continuously. FIXDMACS alarms and FIRUS alert appropriate personnel.

**(2) Cold flask failure, Cryostat windows intact**

<u>Initiation:</u>

a. Flask overpressure.
b. Cold leak in flask or plumbing.

<u>Automatic Responses:</u>

a. If the FPVAC pressure is above 75 microns, alarms will be triggered on the target control system, alerting shift personnel. A signal will be sent to Accelerator Main Control to shut off beam.
b. When vacuum reaches 100 microns as measured on PT-01-V/PT-101-V, high vacuum valve EP-HIVACH/EP-HIVACD closes. Both the cryocooler compressor and condenser heater will be shutdown.
c. When the vacuum jacket reaches 0.5 psig, SV-01-V/SV-101-V and SV-02-V/SV -102-V open and vents the hydrogen/deuterium to relieve the insulating vacuum jacket.

<u>Results of failure:</u>

a. Any hydrogen/deuterium pumped by the vacuum system will be vented into the Tent.
b. All hydrogen/deuterium from a flask failure is vented from the tent through ventilation ducting.

**(3) Failure of H2/D2 supply cylinder valve or cylinder regulator**

<u>Initiation:</u>

a. Leaking cylinder valve.
b. Leaking cylinder regulator.

<u>Automatic responses:</u>

None. No hydrogen detector will be used outside in the cylinder storage area for this experiment.

<u>Results of failure:</u>

Hydrogen/Deuterium gas will vent into the area outside where the cylinders are stored.

**(4) Failure of $H_2/D_2$ supply line between cylinder regulator and PV-H2SUP**

Initiation:

a. Rupture of line.
b. Leak in line due to physical damage.
c. Leaking fittings in line.

Automatic responses:

The excess flow valve, EFV-01-H/EFV-101-D, will stop the flow of hydrogen/deuterium. The excess flow valves are located outdoors, near the supply cylinders.

Results of failure:

a. Supply lines for this experiment are copper tubing which run along the concrete shielding blocks. They are well protected against physical damage.
b. If a failure occurs during filling, hydrogen/deuterium would escape into the NM4 building. Small leaks would be undetected. A maximum of about 200 standard cubic feet (scf) of hydrogen/deuterium would be caught in the ceiling of Building from this failure.
c. The hydrogen/deuterium cylinder is valved off at all times except during filling, limiting the amount of hydrogen/deuterium that could leak during normal operations.

**(5) Failure of $H_2/D_2$ supply line from pump cart to target.**

Initiation:

a. Leak in fittings.
b. Physical damage to lines.
c. Rupture of lines.

Automatic Responses:

a. Target hydrogen/deuterium pressure will drop to 14.3 psia regardless of heater controller setting.
b. If the leak is large enough or directly under the hydrogen detector, it will alarm to alert the operators of the problem. At most a leak will release 200 scf of hydrogen into the NM4 building or the Tent. The tent is equipped with a ventilation fan with a capacity of 1300 cfm air.

c. The line will be valved off (MV-14-H/MV-114-D) except when filling the target.

Results of failure:

a. Supply line to the target is made of ¼" copper tubing, stainless steel flex lines, and fittings. The lines are generally routed along the wall and damage is unlikely.
b. If failure occurs during filling, hydrogen/deuterium would escape into the NM4 building. Small leaks would be undetected. A maximum of about 200 scf of hydrogen/deuterium would be caught in the ceiling of Building from this failure.
c. The hydrogen detector in the ceiling of the tent may see the leak and warn the operators and FIRUS.

**(6) Loss of AC Power**

Initiation:

a. Power outage in area (scheduled or unscheduled).
b. Power outage on Main site.

Automatic Responses:

a. Uninterruptible Power System (UPS) allows control of PV-H2VV/PV-D2VV.
b. All other electronically controlled valves close.
c. All vacuum pumps, compressors, and refrigerators stop.
d. The proton beam will stop.
e. Target motion stops.

Results of failure:

a. Insulating vacuum begins to spoil. No refrigeration is available.
b. Liquid in the targets begins to vaporize. SV-02-H/SV-102-D and SV-03-H/SV-103-D protects system from increasing in pressure higher than 10 psig.

**(7) Restoration of AC Power**

Initiation:

a. Power restored to area.

Automatic Responses:

a. Vacuum system will attempt to restore itself.

b. Refrigerators and compressors remain off.
c. Target table motion will not restart.

Results of failure:

a. Unless the power outage is of very short duration and the refrigerators are restarted, hydrogen/deuterium will be vented.
b. Pressures in the target flask volumes must be checked to determine if SV-02-H/SV-102-D and SV-03-H/SV-103-D have lifted and, if so, re-seated. If the pressure in the target is near 14.3 psia, then the valve must be re-seated and the target re-purged before filling. This scenario is now much less likely since the addition of PV-H2VV/PV-D2VV.
c. The control system will attempt to restart itself if the duration of power loss was longer than what the UPS would have allowed. The control system PC remains off and will need to be restarted.
d. The heater controller will attempt to restart itself, but power to the heater will be set to zero initially. The control system will not automatically restart the PID control.

**(8) Loss of valve-operating gas (air/nitrogen) pressure.**

Initiation:

a. Leakage in the valves, lines, or fittings or excessive use of the valves. See also, E906 Emergency Procedures: Loss of Air/Nitrogen for Valves.
b. Failure of air compressor and depletion of nitrogen bottle.

Automatic Responses:

a. An alarm will sound to notify shift operators that the pneumatic pressure is low.

b. When the pneumatic pressure is less than 20 psig, EP-H2PURGE/EP-D2PURGE, EP-RUFVLVH/EP-RUFVLVD, and EP-FORVLVH/EP-FORVLVD close. Valves close due to force of actuator spring. EP-HIVACH/EP-HIVACD (high vacuum valve) remains in the open state.

c. PV-H2SUP/PV-D2SUP and PV-H2FILL/PV-D2FILL close. Valves close due to force of actuator spring.

Results of failure:

a. Vacuum in the target vacuum jacket will spoil, increasing heat load to the target.
b. Hydrogen/Deuterium may be vented from the target.

**(9) Failure of heater control circuit.**

Initiation:

a. Open heater circuit in the target.
b. Failure of the pressure sensing circuit.
c. Failure of the heater controller.

Automatic responses:

Heater power alarm will trip.

Results of failure:

a. If power output from the controller exceeds the desired power, target pressure will rise and target will vent if the pressure exceeds the vent valve or relief valve set pressures.
b. If power output from controller is less than the desired power, target pressure will decrease. An alarm on the PLC will alert the target operators if the target pressure begins to go sub-atmospheric, or the heater controller power goes above its HI and HIHI setpoints.
c. Operator control maybe required to adjust heater power.

**(10) Failure of pressure transducer circuit.**

Initiation:

a. Failure of pressure transducers, PT-H2VENT/PT-D2VENT.
b. Failure of readout circuits.

Automatic Responses:

a. PT-H2VENT/PT-D2VENT is used for the input signal to the heater control and PV-H2VV/PV-D2VV control. PT-H2SUP/PT-D2SUP will be used for backup controls for the heater and PV-H2VV/PV-D2VV action. The heater control will act on the erroneous signal. If the signal fails low, PV-H2VV/PV-D2VV will not open. If it fails high, PV-H2VV/PV-D2VV will open and vent hydrogen/deuterium.

Results of failure:

a. Target Pressure will be unknown. The heater circuit will act on the erroneous signal and the target will either rise or fall in pressure in response to the heater output. See section 9. If PV-H2VV/PV-D2VV does not open, the hydrogen/deuterium must vent through SV-02-H/SV-102-D. Temperature sensors will be monitored for agreement with pressure transducers.

## I. ODH ANALYSIS

**SeaQuest Building**

Fluids to be in use with the E906 Target System include deuterium, hydrogen, helium and nitrogen. The hydrogen and deuterium cylinders are to be located inside an explosion-proof outdoor storage shelter which is a part of the NM4 Building. The cylinders of non-flammable gas will also be located inside the gas shed. During target filling an $LN_2$ dewar will be in the target service area. At any given time, one nitrogen cylinder will be in use in the target service area. All transfer lines from the gas cylinders into the SeaQuest Hall will be metal. A single spare cylinder of each of these gases may be stored locally. Each cylinder contains roughly 200 to 250 scf of gas. The gas systems are not common and are therefore unlikely to be released simultaneously. If a deuterium, or hydrogen gas supply system were to leak gas indoors, the gas would escape into the very large SeaQuest Hall. The volume of the gas inside the cylinders (250 scf) is small compared to the volume of the building (313,000 $ft^3$) and would not present an ODH condition. The nitrogen from one cylinder released and mixed uniformly inside the SeaQuest Hall would reduce the oxygen concentration by less than 1%. The Building is thus ODH class 0.

Unlike the E866 Target System, there are no external helium lines/cylinders feeding the refrigerator. However, a metal flexible line containing helium will be connected between the compressor and the cryo-cooler coldheads. The amount of helium contained in these metal flexible lines is approximately 3.3 scf of gas. In case of rupture of these lines, the reduction in oxygen concentration would be negligible. When the cryogenic compressors need to be recharged with helium, a helium cylinder of 200 scf will be brought into the hall. The volume of the gas inside the cylinders is small compared to the volume of the building and would not present an ODH condition. The helium from one cylinder released and mixed uniformly inside the SeaQuest Hall would reduce the oxygen concentration by less than 1%. The Building is thus ODH class 0.

**INSIDE THE TENT**

The worst condition from a single flask failure would release 2.2 liters of liquid hydrogen, or approximately 60 scf of gas. The tent exhaust fan has a ventilation rate of 1300 scfm which is significantly higher than the worst case scenario gas release rate.

The E906 refrigerator will contain 3.3 scf of helium in its helium transfer lines. In the case of a rupture, the reduction in oxygen concentration is negligible. Therefore, ODH classification will be 0

# E906 Hydrogen Safety Analysis

If hydrogen or deuterium were to leak inside the tent it will vent through the tent exhaust fan. The amount of hydrogen from one of the targets mixed perfectly with air is equivalent to 0.36 lbs. of TNT. This value is based on a TNT equivalent of 1 lb. TNT = 1 lb. $H_2$ from NBS Report 10 734 "Explosion Criteria for Liquid Hydrogen Test Facilities", Hord. If a full cylinder were to vent into the NM4 Building and mix perfectly with air, its explosive equivalent is equal to 1.2 lbs. of TNT. Any venting from the target flask or its vacuum shell is expected to be vented through the tent ventilation system. All reliefs are adequately sized as is the ventilation ducting.

The vacuum pump carts and cold traps will be located along the east wall of SeaQuest Hall next to the beamline near the targets. The hydrogen and deuterium cylinders will be located outside the Hall on the ground level under cover. In consideration of the presence of hydrogen, the Guidelines section II.F.2.a. is followed. We will take the following precautions in this regard:

(1) Warning signs will be posted alerting personnel of hydrogen gas in the area and that ignition sources are not allowed.

(2) The phone number and pager number of the target experts will be posted such that if a hydrogen target expert is required, the shift crew will be able to contact one. The shift crew will have access to a copy of the E906 $LH_2$ Target Safety Report which includes the Operating and Emergency Procedures.

(3) No combustibles or ignition sources will be allowed in the area of the hydrogen cylinders. No welding will be allowed within 33 feet without the Particle Physics Division Office approval.

(4) Cylinders will be properly secured. Full or empty bottles not in use will be promptly removed and stored in a designated storage area. Concrete bumpers will be installed to keep automobiles at a distance from the cylinders.

(5) The hydrogen supply lines have an excess flow valve installed outdoors. Each cylinder uses an appropriate pressure regulator. Each supply line also includes a relief valve SV-02-H set for 10 psig in order to protect the flasks.

(6) Hydrogen supply lines will be leak checked at 90% of the circuit relief pressure.

(7) The hydrogen lines and ventilation exhaust ducting will be identified with labels.

(8) Hydrogen lines will be metallic and will be appropriately installed and supported.

## J. DESIGN CALCULATIONS/MATERIAL SPECIFICATIONS

### E906 STAINLESS STEEL FLASK STRESS CALCULATIONS

The E906 Target System will re-use the target flasks used for the E866 Target System. Refer to pages 63-72 of the E866 Target Safety Report, or pages 56-65 of the E906 Target Safety Report.

Spare flasks are now being fabricated. Material certification sheets and the results of new joint and flask tests will be submitted to the Safety Committee for approval prior to installation.

# E-866 Stainless Steel Flask Stress Calculations

D. Allspach
October 17, 1995

The following calculations yield the maximum allowable working pressures of a flask constructed using 0.003 in. thick 304 Stainless Steel for the cylindrical shell and 0.002 in. thick 304 Stainless Steel for the hemispherical heads. The Maximum Allowable Stress, $S_a$, used in these calculations is taken as 18,800 psi. The allowable stress is calculated as 1/4 of the ultimate tensile strength of the material. Regarding the joint efficiency, please reference the *E866 Stainless Steel Flask Joint Testing* document.

*Circumferential Stress on Cylinder Under Internal Pressure:*
Formula taken from ASME Boiler and Pressure Vessel Code, Sec. VIII, Div. 1, UG-27(c,1).

| | |
|---|---|
| $E = 1.0$ | Joint Efficiency |
| $t = 0.003$ in. | Stainless Steel Thickness |
| $P$ | Maximum Allowable Working Pressure |
| $R = 1.5$ in. | Flask Radius |

$$P = S_aEt/(R + 0.6t)$$

$$P = (18,800)(1)(0.003)/[1.5 + (0.6)(0.003)]$$

$$P = 37.6 \text{ psid}$$

*Longitudinal Stress on Cylinder Under Internal Pressure:*
Formula taken from ASME Boiler and Pressure Vessel Code, Sec. VIII, Div. 1, UG-27(c,2).

$$P = 2S_aEt/(R - 0.4t)$$

$$P = (2)(18,800)(1)(0.003)/[1.5 - (0.4)(0.003)]$$

$$P = 75.3 \text{ psid}$$

Each of these allowable pressures exceed the suggested MAWP of 25 psid for target flasks by the Target Guidelines. Thus, 0.003 in. thick 304 S.S. is acceptable for the cylindrical portion of the flask.

*Hemispherical Heads with Pressure on Concave Side:*
Formula taken from ASME Boiler and Pressure Vessel Code, Sec. VIII,

Div. 1, UG-32(f).

| | |
|---|---|
| E = 1.0 | Joint Efficiency |
| t = 0.002 in. | Stainless Steel Thickness |
| P | Maximum Allowable Working Pressure |
| L = 1.5 in. | Inside Crown Radius |

$P = 2S_aEt/(L + 0.2t)$

$P = (2)(18{,}800)(1)(0.002)/[(1.5) + (0.2)(0.002)]$

$P = 50.1$ psid

This allowable pressure exceeds the suggested MAWP of 25 psid for target flasks by the Target Guidelines. Thus, 0.002 in. thick 304 S.S. hemispherical heads are acceptable for this flask.

**Flask Maximum Allowable Working Pressure:**

| Calculation | Maximum Pressure |
|---|---|
| Circumferential | 37.6 psid |
| Longitudinal | 75.3 psid |
| Heads | 50.1 psid |
| **MAWP** | **37.6 psid** |

*Stress due to Liquid Weight and Table Motion:*

Both the liquid hydrogen and liquid deuterium targets are located on a linear motion table (see Fermilab drwg. # 9205.100-MD-58662). The table is driven by a stepping motor and has the following calculated maximum velocity and acceleration.

Stepping motor steps per revolution = 200
Controller maximum half-steps per second = 20,000
(10,000 steps/sec)/(200 steps/rev) = 50 revolutions per second
Threaded drive shaft has five threads per inch = 5 rev/inch of linear motion
Maximum table speed = (50 rev/sec)/(5 rev/inch) = 10 inches per second

Assume table is moving at top speed and power fails. Assume table stops in 0.2 seconds.

$$a = \frac{V_f - V_i}{\Delta t} = -50 \text{ in/sec}^2 = -4.167 \text{ ft/sec}^2$$

As liquid deuterium is heavier than liquid hydrogen, the following calculations assume liquid deuterium in the flask. The liquid deuterium weight inside the flask is roughly 1 pound.

$F = ma = (1\ \text{lb}/32.2\ \text{ft/sec}^2)(4.167\ \text{ft/sec}^2) = 0.13\ \text{lbf}$

For a thin cylinder, $I = \pi R^3 t = 0.0318\ \text{in}^4$
where, $R = 1.5$ inches
$t = 0.003$ inches

Also, $c = 1.5$ inches.

The bending moment can be calculated from Roark and Young, Table 3, case 1a. $M = 2.16$ in-lbs. The bending stress in the horizontal plane on the flask due to deceleration of the targets from top speed to zero in 0.2 seconds is the following:

$$\textit{Stress due to Table Motion} = \sigma = \frac{M}{I/c} = \frac{2.16}{\left(0.0318/1.5\right)} = 102\ \text{psi}$$

The weight distribution of the liquid deuterium over the length of the flask is 0.05 lb/in, where the weight is about 1 lb and the total flask length is 20 inches. From Roark and Young, Table 3, case 2a, the maximum bending moment can be determined. This stress on the flask is in the vertical direction.

$$M_{max} = \frac{-w_a l^2}{2} = \frac{(0.05)(16.625)^2}{2} = 6.91\ \text{in-lbs; where, } w_a = 0.05\ \text{lb/in}, \quad l = 16.625\ \text{inches}$$

$$\textit{Stress due to Liquid (Deuterium) Weight} = \sigma = \frac{M}{I/c} = \frac{6.91}{\left(0.0318/1.5\right)} = 326\ \text{psi}$$

The combined effect of these two conditions is 342 psi directed 72.6 degrees downward from the horizontal plane. Thus, the additional stress imposed on the flask due to the conditions of table motion and liquid weight is insignificant.

# INVOICE

27810

E-866

THIN METAL SALES, INC.
15047 Sierra Bonita Lane
Chino, CA 91710
(909) 393-2273

Fermilab
P.O. Box 500
ATTN: Accounting
Batavia, IL 60510

SHIPPED TO

Fermilab
Kirk Road & Wilson Street
ATTN: Receiving
Batavia, IL 60510

| INVOICE DATE | DATE SHIPPED | OUR ORDER NO | YOUR ORDER NO | TERMS | F.O.B. | SALESPERSON | SHIPPED VIA |
|---|---|---|---|---|---|---|---|
| 03/20/95 | 03/20/95 | 24823 | S47040 | Net 30 | Chino | FER05 | UPS |

| QUANTITY ORDERED | QUANTITY SHIPPED | DESCRIPTION | PRICE | AMOUNT |
|---|---|---|---|---|
| | 5 lb | .002 x 24½" T304 Annealed Stainless | | |

954351

Specification: ASTM-A-240-94A, ASTM-A-666-94A,T302 AMS-5516L Size: 0.00200
Specification: T304 AMS-5513F Type: T302/304

Heat# 864141 Mill Source: ALLEGHENY

| | |
|---|---|
| Condition | ANNEALED |
| Rockwell | KN 125 |
| Ultimate Tensile (psi) | 105,000 |
| Yield Strength @ .2% offset (psi) | 46,000 |
| Percent Elongated in 2 inches | 40% |
| Bend Test | OK |
| ASTM Grain Size | 8 |
| Embrittlement Test | OK |

| Co | C | Mn | P | S | Si | Cr | Ni | Mo |
|---|---|---|---|---|---|---|---|---|
| | .06 | 1.86 | .026 | .0005 | .44 | 18.39 | 9.17 | .40 |

| Al | Cu | Ti | Cb&Ta | N2 | O2 | Fe | V | Sn |
|---|---|---|---|---|---|---|---|---|
| | .41 | | | .05 | | | | |

We certify this to be a true and just copy of the chemical and mechanical properties as recorded in our company files.

THIN METAL SALES, INC.

R.F. Briggs, Jr.
Quality Manager

954351

E-866

# INVOICE

27810

THIN METAL SALES, INC.
15047 Sierra Bonita Lane
Chino, CA 91710
(909) 393-2273

Fermilab
P.O. Box 500
ATTN: Accounting
Batavia, IL 60510

SHIPPED TO

Fermilab
Kirk Road & Wilson Street
ATTN: Receiving
Batavia, IL 60510

| INVOICE DATE | DATE SHIPPED | OUR ORDER NO | YOUR ORDER NO | TERMS | F.O.B | SALESPERSON | SHIPPED VIA |
|---|---|---|---|---|---|---|---|
| 03/20/95 | 03/20/95 | 24823 | S47040 | Net 30 | Chino | FER05 | UPS |

| QUANTITY ORDERED | QUANTITY SHIPPED | DESCRIPTION | PRICE | AMOUNT |
|---|---|---|---|---|
| | 5 lb | .002 x 24½" T304 Annealed Stainless | | |
| | 5 lb | .003 x 24½" T304 Annealed Stainless | | |

944179

pecification: T302 AMS-5516L
pecification: T304 AMS-5513F

Type: T302/304

Size: 0.00300

eat# 862622

Mill Source: ALLEGHENY

| | |
|---|---|
| ondition | ANNEALED |
| ockwell | KN 120 |
| ltimate Tensile (psi) | 88,000 |
| ield Strength @ .2% offset (psi) | 32,000 |
| ercent Elongated in 2 inches | 45% |
| end Test | OK |
| STM Grain Size | 8 |
| mbrittlement Test | OK |

| Co | C | Mn | P | S | Si | Cr | Ni | Mo |
|---|---|---|---|---|---|---|---|---|
| | .05 | 1.87 | .28 | .001 | .47 | 18.45 | 9.13 | .35 |

| Al | Cu | Ti | Cb&Ta | N2 | O2 | Fe | V | Sn |
|---|---|---|---|---|---|---|---|---|
| | .40 | | | .04 | | | | |

e certify this to be a true and just copy of the chemical and mechanical roperties as recorded in our company files.

THIN METAL SALES, INC.

R.F. Briggs, Jr.
Quality Manager

RF Briggs Jr

.79

# Stainless Steel Flask Relief Sizing

D. Allspach
February 16, 1995

The stainless steel target flask is relieved by an Anderson Greenwood relief valve. The flask surface area must first be calculated in order to obtain the rate of heat flow to the vessel. From this rate of heat transfer, and the heats of vaporization of $H_2$ and $D_2$, the mass flow rate of the vaporizing $H_2$ or $D_2$ can be calculated, as well as the corresponding pressure drop in the lines. The relief valve may be sized for this flow rate.

*Vessel Dimensions:*

| | |
|---|---|
| R = 1.5 in | Cylinder Radius |
| B = 20.0 in | Vessel Length (Total) |
| h = 0.75 in | Depth of ellipsoidal head |
| L = 18.5 in | Cylinder Length |
| S | Surface Area of one head |
| A | Vessel Surface Area |
| K | Radius of dished head |
| V | Vessel Volume |
| Y | Volume of one head |
| MR = 3.0 in | Principle Radius of Head |
| mR = 0.75 in | Knuckle Radius |

The formulas below are taken from C.B.I. Bulletin #594.

$K = M - [(M-1)(M+1-2m)]^{1/2}$
$M = 2.0, \ m = 0.5$
$K = 0.586$

$S = \pi R^2[1+K^2(2-K)]$
$S = 10.5$ sq. in.
$A = 2\pi RL + 2S$
$A = 195 \text{ in}^2 = 1.35 \text{ ft}^2$

$Y = (2/3)\pi KR^3$
$Y = 4.14 \text{ in}^3$
$V = \pi R^2L+2Y$
$V = 139 \text{ in}^3 = 2.28$ liters

*Required Mass Flow Rate :*

| | |
|---|---|
| $q' = 3500$ Btu/(hr-ft$^2$) | Heat Flux to Vessel (Cryogenic Systems, Barron) |
| $S = 1.35$ ft$^2$ | Vessel Surface Area |
| $Q$ | Heat Transfer Rate to Vessel |
| $\Delta H' = 434.2$ J/g | $H_2$ Heat of Vaporization |
| $\Delta H'' = 314.6$ J/g | $D_2$ Heat of Vaporization |
| $m'$ | Mass Flow Rate |

$Q = q'S$
$Q = 4725$ Btu/hr $= 1384$ W
$m' = Q/\Delta H$
$m'(H_2) = 3.2$ g/s $= 25$ lbs/hr
$m'(D_2) = 4.4$ g/s $= 35$ lbs/hr

*Required Relief Valve Orifice :*

Symbols and formula from Anderson Greenwood catalog, "Series 80 Relief Valves", p. 6.

| | |
|---|---|
| $W(H_2) = 25$ lbs/hr | Mass Flow Rate ($m'$) of $H_2$ |
| $W(D_2) = 35$ lbs/hr | Mass Flow Rate ($m'$) of $D_2$ |
| $T = 530$ °R | Absolute Temperature |
| $M(H_2) = 2.0$ | Molecular Weight of $H_2$ |
| $M(D_2) = 4.0$ | Molecular Weight of $D_2$ |
| $Z = 1.0$ | Compressibility |
| $K = 0.816$ | Valve Discharge Coefficient |
| $P1 = 25.7$ psia | Pressure at Valve Inlet |
| $C = 356$ | Gas Constant |
| $A$ | Required Area of Orifice |

$A = W(TZ)^{1/2}/CKP1(M)^{1/2}$
$A(H_2) = 0.055$ in$^2$
$A(D_2) = 0.053$ in$^2$

An Anderson-Greenwood type 83 relief valve with a 3/8 inch orifice diameter (0.110 in$^2$ orifice area) will be sufficient for each target.

*Actual Flow Capacity of Relief Device:* (Subsonic flow formula)

| | |
|---|---|
| $W$ | Mass Flow Rate |
| $P_1 = 25$ psia | Valve Inlet Pressure |
| $P_2 = 15$ psia | Valve Outlet Pressure |
| $M(H_2) = 2.0$ | Molecular Weight of Hydrogen |
| $M(D_2) = 4.0$ | Molecular Weight of Deuterium |
| $T = 530$ °R | Flow Temperature |

| | |
|---|---|
| $Z = 1$ | Compressibility |
| $A = 0.110$ sq. in. | Valve Orifice Area |
| $K = 0.816$ | Valve Coefficient of Discharge |
| $k = 1.404$ | Ratio of Specific Heats |
| $m'$ | Actual Mass Flow Capacity of Relief Device |

$W = (735)AKP_1(M)^{1/2}[(k/(k-1))((P_2/P_1)^{(2/k)} - (P_2/P_1)^{((k+1)/k)})]^{1/2}/(TZ)^{1/2}$
$W(H_2) = 48.8$ lbs/hr $= 6.15$ g/s $H_2$
$W(D_2) = 68.6$ lbs/hr $= 8.64$ g/s $D_2$

Note: The following calculations show the pressure drops through the vent lines for the actual flow capacity of the relief device.

*Pressure Drop in Line from Flask to Cond. Pot:*
Assuming cold line (Saturation temperature of $H_2$ or $D_2$)
1/2 in. stainless tubing of length 3.0 ft; I.D. = 0.402 in = 1.02 cm
Neglect the change in height (since it is small) and minor losses (since there are no sharp bends). The properties below are for 25 psia and saturated vapor.

| | |
|---|---|
| $\rho(H_2) = .00216$ g/cc | Density of $H_2$ |
| $\rho(D_2) = .00375$ g/cc | Density of $D_2$ |
| $\mu(H_2) = 1.25 \times 10^{-5}$ g/cm-s | Viscosity of $H_2$ |
| $\mu(D_2) = 1.55 \times 10^{-5}$ g/cm-s | Viscosity of $D_2$ |
| $v$ | Velocity |
| $f$ | Friction Factor |
| $D = 1.02$ cm | Inner Diameter of tubing |
| $\varepsilon = 0.0015$ mm | Roughness of Drawn Tubing |
| $\Delta P1$ | Pressure Drop from Vessel to Cond. Pot |
| $L = 91.4$ cm | Length of Pipe |
| $m'(H_2) = 6.15$ g/s | Actual Mass Flow Capacity of Valve |
| $m'(D_2) = 8.64$ g/s | Actual Mass Flow Capacity of Valve |

$Re = \rho v D/m = 4m'/D\pi\mu$
$Re(H_2) = 6.14 \times 10^5 >> 2300$, therefore, Turbulent.
$Re(D_2) = 6.96 \times 10^5 >> 2300$, therefore, Turbulent.
$f(H_2) = 0.0146$ ( From Moody Chart, $\varepsilon/D = 0.000147$ )
$f(D_2) = 0.0145$ ( From Moody Chart, $\varepsilon/D = 0.000147$ )

$v = 4m'/\pi\rho D^2$
$v(H_2) = 3484$ cm/s
$v(D_2) = 2820$ cm/s

$\Delta P = \rho v^2 f L/2D$
$\Delta P1(H_2) = 1715$ Pa = 0.25 psi
$\Delta P1(D_2) = 1937$ Pa = 0.28 psi

*Pressure Drop in Line from Cond. Pot to Relief Valve:*
1/2 inch stainless tubing, 3.5 ft long; I.D. = 1.02 cm. Find the temperature of the fluid in this length of bare tubing for P = 25 psia:

| | |
|---|---|
| q' = 3500 Btu/(hr-ft$^2$) = 1.1 W/cm$^2$ | Heat Flux to Uninsulated Tube |
| A = $\pi$(0.5 in)(42 in) = 66 in$^2$ = 426 cm$^2$ | Outside Surface Area of Tube |
| Q = 467 W | Heat Transfer to Tube |
| m'($H_2$) = 6.15 g/s; $\Delta$h = Q/m' = 76 J/g | Energy Increase of Hydrogen |
| m'($D_2$) = 8.64 g/s; $\Delta$h = Q/m' = 54 J/g | Energy Increase of Deuterium |
| $h_1(H_2)$ = 198.5 J/g | Saturated Vapor Enthalpy of $H_2$ |
| $h_1(D_2)$ = 196.9 J/g | Saturated Vapor Enthalpy of $D_2$ |
| $h_2(H_2)$ = 198.5 + 76 = 275 J/g | Enthalpy of $H_2$ at Relief Valve |
| $h_2(D_2)$ = 196.9 + 54 = 251 J/g | Enthalpy of $D_2$ at Relief Valve |
| T($H_2$) = 29 K | Temperature of $H_2$ at Relief Valve |
| T($D_2$) = 37 K | Temperature of $D_2$ at Relief Valve |

To be slightly conservative, assume that the temperature of both the $H_2$ and $D_2$ flowing through the tube is at 50 K. Neglect the change in height (since it is small) and minor losses (since there are no sharp bends). The properties below are for 25 psia and 50 K.

| | |
|---|---|
| $\rho(H_2)$ = 0.8479 E-3 g/cc | Density of $H_2$ |
| $\rho(D_2)$ = 0.169 E-2 g/cc | Density of $D_2$ |
| $\mu(H_2)$ = 1.53 E-5 g/cm-s | Viscosity of $H_2$ |
| $\mu(D_2)$ = 2.14 E-5 g/cm-s | Viscosity of $D_2$ |
| v | Velocity |
| $f$ | Friction Factor |
| D = 1.02 cm | Inner Diameter of tubing |
| $\varepsilon$ = 0.0015 mm | Roughness of Drawn Tubing |
| $\Delta$P2 | Pressure Drop from Vessel to Cond. Pot |
| L = 107 cm | Length of Pipe |
| m'($H_2$) = 6.15 g/s | Actual Mass Flow Capacity of Valve |
| m'($D_2$) = 8.64 g/s | Actual Mass Flow Capacity of Valve |

$Re = \rho v D/\mu = 4m'/D\pi\mu$
$Re(H_2) = 5.02 \times 10^5 >> 2300$, therefore, Turbulent.
$Re(D_2) = 5.04 \times 10^5 >> 2300$, therefore, Turbulent.

$f(H_2) = 0.015$ ( From Moody Chart, $\varepsilon/D = 0.000147$ )
$f(D_2) = 0.015$ ( From Moody Chart, $\varepsilon/D = 0.000147$ )

$v = 4m'/\pi\rho D^2$
$v(H_2) = 8876$ cm/s
$v(D_2) = 6257$ cm/s

$\Delta P = \rho v^2 f L/2D$
$\Delta P2(H_2) = 5256$ Pa $= 0.76$ psi
$\Delta P2(D_2) = 5206$ Pa $= 0.76$ psi

*Total Pressure Drop in Line:*
$\Delta P_{total}(H_2) = \Delta P1 + \Delta P2 = 1.01$ psi
$\Delta P_{total}(D_2) = \Delta P1 + \Delta P2 = 1.04$ psi

These pressure drops are less than the 2.0 psi blowdown of the relief valve. The valve blowdown is set at 20% of the valve set pressure.

## VACUUM JACKET STRESSES

The E906 Target System will re-use the vacuum jacket used for the E866 Target System. For safety issues relating to its stress test, volume, and relief mechanism, refer to pages 73-74 of the E866 Target Safety Report, or pages 67-68 of the E906 Target Safety Report.

1

# Vacuum Jacket Stresses

D. Allspach
March 6, 1995

The cylindrical portion of the vacuum vessel housing the target flask has a 5 inch outer diameter, a length of about 15.5 inches and a wall thickness of 0.125 inches. On the upstream end of the cylindrical shell is attached a heavy wall aluminum target transition block. A flange is located on the downstream end. Reference Fermilab drawing # 2727.866-MD-58635. These vessel components are made of 6061-T6 Aluminum Alloy.

*Cylindrical Shell, Internal Pressure:* Formulae are obtained from the ASME Boiler and Pressure Vessel Code, Sec. VIII, Div. 1, UG-27.

| | |
|---|---|
| t = 0.125 in. | Actual Shell Thickness |
| E = 0.6 | Weld Efficiency |
| S = 10,500 psi | Maximum Allowable Stress for Drawn Seamless Tube |
| R = 2.375 in. | Inside Shell Radius |
| $P_{min}$ = 15 psid | MAWP of Vessel (Target Guidelines, II.D.1.c.(i)) |
| P | Actual Maximum Allowable Pressure |

*Circumferential Stress: UG-27(c,1)*
P = SEt / (R + 0.6t)
P = (10,500)(0.6)(0.125)/[2.375 + (0.6)(0.125)]
P = 321 psid

*Longitudinal Stress: UG-27(c,2)*
P = 2SEt / (R - 0.4t)
P = (2)(10,500)(0.6)(0.125)/[2.375 - (0.4)(0.125)]
P = 677 psid

*Cylindrical Shell, External Pressure:* Formulae and variables obtained from the "ASME Boiler and Pressure Vessel Code", Sec. VIII, Div. 1, UG-28 and App. 5.

| | |
|---|---|
| $D_o$ = 5.0 in. | Outer Shell Diameter |
| L = 15.5 in. | Length of Shell |
| t = 0.125 | Shell Thickness |
| A | Factor Obtained from Fig. 5-UGO-28.0 |
| B | Factor Obtained from Fig. 5-UNF-28.30 |
| P | Max. Allowable External Pressure |
| E = 10.0 E6 psi | Modulus of Elasticity |

*Cylindrical Shell, External Pressure (cont.):*

$D_o / t = 40 > 10$ therefore, use UG-28(c,1).

Step 1: $L / D_o = 3.1$; $D_o / t = 40$.
Steps 2-3: From Fig. 5-UGO-28.0, A = 0.0016
Steps 4-5: From Fig. 5-UNF-28.30, B = 7,500
Step 6:

$P = 4Bt / 3D_o$
$P = (4)(7500)(0.125)/[(3)(5.0)]$
P = 250 psid

**Maximum Allowable Working Pressures:**

| Calculation | Internal Press. | External Press. |
|---|---|---|
| Shell | ------- | 250 psid |
| Shell, Circumferential | 321 psid | ------- |
| Shell, Longitudinal | 677 psid | ------- |
| **MAWP, External** | ------ | **250 psid** |
| **MAWP, Internal** | **321 psid** | ------- |

The Maximum Allowable External Pressure is 250 psid. This is greater than the 7.5 psid required external pressure when using the ASME allowable stress. Thus, the Fermilab ES&H Manual Chapter 5033, "Vacuum Vessel Safety", which requires a minimum collapse pressure of 30 psid (15 psid collapse pressure with a safety factor of two) is satisfied; therefore, the vessel meets Fermilab's vacuum vessel external pressure requirement.

The Maximum Allowable Internal Pressure is 321 psid. This is greater than the 15 psid minimum required by "The Design, Fabrication, Testing, Installation, and Operation of $LH_2$ Targets", II.D.1.c.(i); therefore, the vessel meets Fermilab's vacuum vessel internal pressure requirement.

# TITANIUM WINDOW STRESS

The E906 Target System will re-use the titanium windows used for the E866 Target System. Refer to pages 75-86 of the E866 Target Safety Report, or pages 70-81 of the E906 Target Safety Report.

New titanium windows will be fabricated. Material certification sheets will be submitted to the Safety Committee for approval prior to installation.

# Titanium Window Stress

D. Allspach

February 14, 1995

The E866 target beam windows are to be fabricated from a titanium alloy, Ti 15-3 (Ti-15V-3Cr-3Sn-3Al). The downstream flange and a flange on the transition block hold the thin metal windows in position. The "beam diameter" of each window is 4.25 inches (diameter to calculate window thickness = 4.5 inches).

*Window Thickness:* Fermilab ES&H Manual Chapter 5033, "Vacuum Vessel Safety", references the Mechanical Safety Subcommittee Guidelines for the Design of Thin Windows at Fermilab (TM-1380). Formulas in this memo are taken from Roark and Young for combined bending and diaphragm stresses for circular plates (Chapter 10 of the Fifth Edition). Our flanges have a 1/8 inch edge radius as is required by paragraph II.E.2.a. of the Target Guidelines. Thus, 1/4 inch (2 x 1/8 inch) is added to the "beam diameter" for the calculations below. Edge conditions are fixed and held.

| | |
|---|---|
| $S_u$ = 121,100 psi | Minimum Ultimate Strength |
| $S_y$ = 107,000 psi | Minimum Yield Strength |
| q = 15 psid | Actual pressure applied to window |
| E = 13.4 E6 psi | Minimum Modulus of Elasticity |
| $\upsilon = 0.3$ | Poisson's ratio |
| a = 2.25 inches | Window radius |
| t | Window thickness |
| y | Window deflection |

Using t = 0.0055 inches in the formula below, iterations are performed to find the deflection, y, such that the calculated window thickness, $t_{calculated}$, is equal to 0.0055.

$$t_{calculated} = \sqrt[4]{\frac{qa^4(1-\upsilon^2)}{E[(5.33)(y/t)+(2.6)(y/t)^3]}}$$

It is found that for y = 0.122 inches, t = 0.0055 inches. Note that y > t / 2, thus the above formula for diaphragms is valid.

y = 0.122 > t/2 = 0.00275 inches

Given the thickness and deflection, the edge and center stresses are found.

*Stress at Edge:*

$$\sigma_{edge} = E\left(\frac{4}{1-\upsilon^2}\right)\left(\frac{y \times t}{a^2}\right) + E(0.476)\left(\frac{y}{a}\right)^2$$

$$\sigma_{edge} = 26{,}570 \text{ psi}$$

*Stress at Center:*

$$\sigma_{center} = E\left(\frac{2}{1-\upsilon}\right)\left(\frac{y \times t}{a^2}\right) + E(0.976)\left(\frac{y}{a}\right)^2$$

$$\sigma_{center} = 43{,}560 \text{ psi}$$

As found above, the maximum stress is at the center of the window. Given the certified ultimate tensile strength we find this material offers a safety factor of 2.8. Also, we see that the maximum stress is about 40% of the certified yield strength.

It is of interest to compare these safety factors with those the Target Guidelines require for mylar and those which are required in Vacuum Vessel Safety. Paragraph II.E.1.b.(i) of the Guidelines note that the allowable strength for a circular mylar window is to be taken as 2/3 of the yield strength. (Note that, based on tensile testing of mylar at Fermilab, an allowable strength based on 2/3 of the yield strength is approximately equivalent to a safety factor of 2.5 based on the ultimate strength). Vacuum Vessel Safety requires that the smaller of 0.5(ultimate strength) or 0.9(yield strength) be taken as the allowable strength. In consideration of these methods of determining the allowable strength, we find that, for Ti 15-3, using 0.5(ultimate strength) results in the smallest value. It is thus relevant to speak of the safety factor for the E866 windows relative to the ultimate strength of the material. Note that our safety factor of 2.8 exceeds that required for mylar in the Target Guidelines and that required for Vacuum Vessel Safety.

Paragraph II.E.3.a. of the Guidelines require that testing be completed on windows in order to verify their strength. This is viewed as a very important requirement. As a result, testing beyond the requirements of the Guidelines is planned to understand how the Ti 15-3 will perform under various conditions. See safety report insert *Titanium Window Testing*. However, the required burst pressure of 75 psid (implying a safety factor of 5 based on the ultimate strength) for materials other than mylar is an excessively stringent requirement opposing the goal of building a target system conducive to obtaining physics data at a reasonably efficient rate. We propose that this point in the Guidelines be revised (please see insert titled *Proposal for Revision to Target Guidelines Paragraph II.E.3.a. and Other Related Paragraphs*). For the case at hand, we propose, given the information in this document and others supporting it and positive testing results, that Ti 15-3 windows at 0.0055 inch thickness be approved for use in the E866 experiment.

Following is additional information which indicates positive performance of Ti 15-3 for use as E866 vacuum windows.

*Failure Scenario:*

In the case of a flask failure the following conditions exist:

(1) The vacuum container will increase in pressure to a maximum of about 3.5 psig.

(2) The parallel plate reliefs will open, venting hydrogen/deuterium into the tent. The tent exhaust fan will start automatically. $H_2/D_2$ will be vented outdoors.

(3) The initial level of $H_2/D_2$ in the vacuum container will be such that it will cool the titanium windows to cryogenic temperatures.

*Thermal Stress:*

Following is an analysis of the window stress due to thermal contraction in the case of a flask failure. From "Cryogenic Engineering" by B. A. Hands, Fig. 4.5, page 98, we see that the thermal contraction of Titanium from room temperature to 20K is 0.15%. Given the Modulus of Elasticity we can find the stress applied to the window due to this thermal contraction.

$$\sigma_{thermal} = \varepsilon E = 0.0015 in/in \times 13.4E6 psi = 20{,}100 psi$$

This stress is calculated assuming the aluminum flanges holding the windows do not shrink. If uniform contraction is assumed, the actual window thermal stress will be less than that calculated above. In fact, the thermal contraction of aluminum from room temperature to 20K is slightly greater than that of titanium.

This problem was modeled by our Engineering Analysis Group. The model assumes that the edges of the windows are fixed and held (as in TM-1380), they are exposed to cryogenic temperatures and are subsequently loaded to 15 psid. The maximum combined stress on a window under these conditions was found to be about 65,000 psi. Upon examination of the Titanium alloy properties we find that both $S_y$ and $S_u$ increase significantly with lowered temperature. This combined stress value is about 30% of $S_y$ at liquid hydrogen temperature.

If an actual flask failure were to occur, the differential pressure across the window will decrease (from 15 psid external pressure to 3.5 psid internal pressure) as noted above. This decrease in pressure differential will cause the stress component due to pressure to decrease. The combined stress value of 65,000 psi is thus conservative.

The elongation of Ti 15-3 is reduced by approximately 50% when it is cooled from room temperature to liquid hydrogen temperature. The elongation of the Ti 15-3 material is certified at 14.3% at room temperature. Actual elongation calculated for the E866 vacuum windows with 15 psid is less than 0.5%.

The case of a flask failure is not expected to cause the vacuum windows to fail. Thus, the analysis indicates that 0.0055 inch thick titanium alloy vacuum windows are suitable for the E866 targets.

# CERTIFICATE OF TEST



2/1/95 No. 01

**ARNOLD**
THE ARNOLD ENGINEERING COMPANY
A subsidiary of SPS Technologies

**PRECISION ROLLING MILL**
300 West Street Marengo, Illinois 60152
Marengo (815) 568-2471
FAX (815) 568-2477

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Our Order No. R3072
Customer Order No. S25580
Order Date 1/31/95
Date Shipped 2/1/95
Requested Shipping Instructions
UPS

| End Use | Partial or Complete | Quantity Shipped | Description |
|---|---|---|---|
| 85710 | C | 1 Lot (3.0 lbs.) | 15-3-3 Titanium, Annealed<br>.0055 x 10.125 x as rolled width x coil<br>AMS 4914 with standard AECo exceptions |

## CHEMICAL ANALYSIS

MATERIAL AS IS

| No. — Lot No. | C | Mn | P | Sn | Si | Cr | Ni | Mo | ~~XXXXXXXX~~ Y | Va | Al | Fe | ~~Cu~~ Ti | N | H |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T6230H | .011 | .11 | | 2.6 | | 2.8 | | | *.10 | 15.4 | 3.0 | .12 | 75.94 | .016 | .003 |

*DENOTES LESS THAN

## PHYSICAL PROPERTIES

| | Properties in As-Ordered Condition | | | | | Heat Treatable Conditions | | | |
|---|---|---|---|---|---|---|---|---|---|
| Lot No: | Yield Strength | Tensile Strength | Elong % | Hardness | Grain Size | Yield Strength | Tensile Strength | Elong % | Hardness |
| T6230H | 107,000 | 121,100 | 14.3% | 15T915 | ASTM#6.5 | | | | |

Subscribed and sworn to before me

__________Day of________________19__________

We hereby certify that the chemical analysis and physical or mechanical tests reported above are correct as contained in the records of the company.

By George W. Nelson

GEORGE W. NELSON
APPLICATION ENGINEER

FORM ARM-632-43-006

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

# AEROSPACE MATERIAL SPECIFICATION

Submitted for recognition as an American National Standard

SAE AMS 4914A

Issued 1 APR 1984
Revised 1 JUL 1992
Superseding AMS 4914

## TITANIUM ALLOY COLD ROLLED SHEET AND STRIP
## 15V - 3Al - 3Cr - 3Sn
## Solution Heat Treated

1. SCOPE:

1.1 Form:

This specification covers a titanium alloy in the form of sheet and strip.

1.2 Application:

These products have been used typically for parts to be formed in the solution heat treated condition and subsequently precipitation heat treated requiring high strength-to-weight ratio and stability up to 550 °F (288 °C) in the precipitation heat treated condition, but usage is not limited to such applications.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2242 Tolerances, Corrosion and Heat Resistant Steel, Iron Alloy, Titanium, and Titanium Alloy Sheet, Strip, and Plate
MAM 2242 Tolerances, Metric, Corrosion and Heat Resistant Steel, Iron Alloy, Titanium, and Titanium Alloy Sheet, Strip, and Plate
AMS 2249 Chemical Check Analysis Limits, Titanium and Titanium Alloys
AMS 2750 Pyrometry
AMS 2809 Identification, Titanium and Titanium Alloy Wrought Products

2.2 ASTM Publications:

Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM E 8 Tension Testing of Metallic Materials
ASTM E 8M Tension Testing of Metallic Materials (Metric)
ASTM E 112 Determining the Average Grain Size
ASTM E 120 Chemical Analysis of Titanium and Titanium Alloys
ASTM E 290 Semi-Guided Bend Test for Ductility of Metallic Materials

2.3 U.S. Government Publications:

Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-163 Steel Mill Products, Preparation for Shipment and Storage

3. TECHNICAL REQUIREMENTS:

3.1 Composition:

Shall conform to the percentages by weight shown in Table 1, determined by wet chemical methods in accordance with ASTM E 120, by spectrochemical methods, or by other analytical methods acceptable to purchaser.

TABLE 1 - Composition

| Element | min | max | |
|---|---|---|---|
| Vanadium | 14.0 | 16.0 | |
| Chromium | 2.5 | 3.5 | |
| Tin | 2.5 | 3.5 | |
| Aluminum | 2.5 | 3.5 | |
| Iron | -- | 0.25 | |
| Oxygen | -- | 0.13 | |
| Carbon | -- | 0.05 | |
| Nitrogen | -- | 0.05 | (500 ppm) |
| Hydrogen | -- | 0.015 | (150 ppm) |
| Residual Elements, each (3.1.1) | -- | 0.10 | |
| Residual Elements, total (3.1.1) | -- | 0.40 | |
| Titanium | remainder | | |

3.1.1 Determination not required for routine acceptance.

3.1.2 (R) Check Analysis: Composition variations shall meet the requirements of AMS 2249.

3.2 Melting Practice:

3.2.1 (R) Alloy shall be multiple melted; the final melting cycle shall be under vacuum. The first melt shall be by consumable electrode, nonconsumable electrode, electron beam, or plasma arc melting practice. The subsequent melt or melts shall be made using consumable electrode practice with no alloy additions permitted in the last consumable electrode melt.

3.2.1.1 (R) The atmosphere for nonconsumable electrode melting shall be vacuum or shall be argon and/or helium at an absolute pressure not higher than 1000 mm of mercury.

3.2.1.2 (R) The electrode tip for nonconsumable electrode melting shall be water-cooled copper.

3.3 Condition:

Hot rolled with subsequent cold reduction, solution heat treated, descaled, and leveled, having a surface appearance comparable to a commercial corrosion-resistant steel No. 2D finish (See 8.2).

3.4 (R) Heat Treatment:

Product shall be solution heat treated by heating to a temperature within the range 1450 to 1500 °F (788 to 816 °C), holding at the selected temperature within ±25 °F (±14 °C) for 3 to 30 minutes, and cooling at a rate which will produce product meeting the requirements of 3.5 (See 8.3). Pyrometry shall be in accordance with AMS 2750.

3.5 Properties:

The product shall conform to the following requirements:

3.5.1 As Solution Heat Treated:

3.5.1.1 Tensile Properties: Shall be as shown in Table 2 for product 0.125 inch (3.18 mm) and under in nominal thickness, determined in accordance with ASTM E 8 or ASTM E 8M with the rate of strain maintained at 0.003 to 0.007 inch/inch/minute (0.003 to 0.007 mm/mm/minute) through the yield strength and then increased so as to produce failure in approximately one additional minute. When a dispute occurs between purchaser and vendor over the yield strength values, a referee test shall be performed on a machine having a strain rate pacer, using a rate of 0.005 inch/inch/minute (0.005 mm/mm/minute) through the yield strength and a minimum crosshead speed of 0.10 inch (2.5 mm) per minute above the yield strength.

TABLE 2 - Tensile Properties

| Property | Value |
| --- | --- |
| Tensile Strength | 102 - 137 ksi (703 - 945 MPa) |
| Yield Strength at 0.2 % Offset | 100 - 126 ksi (689 - 869 MPa) |
| Elongation in 2 Inches (50.8 mm) or 4D | 12% |

3.5.1.1.1 (R) Tensile property requirements for product over 0.125 inch (0.32 mm) in nominal thickness shall be as agreed upon by purchaser and vendor.

3.5.1.2 Bending: Product 0.125 inch (3.18 mm) and under in nominal thickness shall withstand, without evidence of cracking when examined at 20X magnification, bending in accordance with ASTM E 290 through an angle of 105 degrees around a diameter equal to the bend factor times the nominal thickness of the product, using either V-block, U-channel, or free bend procedure with axis of bend parallel to the direction of rolling. Only one of these tests will be required in routine inspection. In case of dispute, results of bend tests using the V-block procedure shall govern.

TABLE 3 - Bending

| Nominal Thickness Inch | Nominal Thickness Millimeters | Bend Factor |
| --- | --- | --- |
| Up to 0.070, incl | Up to 1.78, incl | 4 |
| Over 0.070 to 0.125, incl | Over 1.78 to 3.18, incl | 5 |

3.5.1.2.1 Bending requirements for product over 0.125 inch (3.18 mm) in nominal thickness shall be as agreed upon by purchaser and vendor.

3.5.1.3 Surface Contamination: The product shall be free of any oxygen-rich layer, such as alpha case, or other surface contamination, determined by the bend test of 3.5.1.2 or other method acceptable to purchaser.

3.5.2 After Precipitation Heat Treatment:

4.4 Reports:

The vendor of the product shall furnish with each shipment a report showing the results of tests for chemical composition of each heat and for the hydrogen content and tensile and bending properties and grain size of each lot, and stating that the product conforms to the other technical requirements. This report shall include the purchase order number, lot number, AMS 4914A, size, and quantity.

4.5 (R) Resampling and Retesting:

If any specimen used in the above tests fails to meet the specified requirements, disposition of the product may be based on the results of testing three additional specimens for each original nonconforming specimen. Failure of any retest specimen to meet the specified requirements shall be cause for rejection of the product represented. Results of all tests shall be reported.

5. PREPARATION FOR DELIVERY:

5.1 (R) Identification:

Shall be in accordance with AMS 2809.

5.2 Packaging:

5.2.1 (R) The product shall be prepared for shipment in accordance with commercial practice and in compliance with applicable rules and regulations pertaining to the handling, packaging, and transportation of the product to ensure carrier acceptance and safe delivery.

5.2.2 For direct U.S. Military procurement, packaging shall be in accordance with MIL-STD-163, Commercial Level, unless Level A is specified in the request for procurement.

6. ACKNOWLEDGMENT:

A vendor shall mention this specification number and its revision letter in all quotations and when acknowledging purchase orders.

7. REJECTIONS:

Product not conforming to this specification, or to modifications authorized by purchaser, will be subject to rejection.

8. NOTES:

8.1 Marginal Indicia:

The (R) symbol is used to indicate technical changes from the previous issue of this specification.

8.2 Commercial corrosion-resistant steel finishes are defined in ASTM A 480/A 480M.

8.3 For nominal thicknesses under 0.1875 inch (4.762 mm), air cooling from the solution heat treatment temperature is usually satisfactory. Fan air circulation is recommended for thicknesses 0.1875 to 0.375 inch (4.762 to 9.52 mm), inclusive. Quenching, usually in water, may be required for thicknesses over 0.375 inch (9.52 mm).

8.4 Definition of "Oil Can":

An excess of material in a localized area of a sheet which causes the sheet to buckle in that area. When the sheet is placed on a flat surface and hand pressure applied to the buckle, the buckle will spring through to the opposite surface or spring up in another area of the sheet.

8.5 Dimensions and properties in inch/pound units and the Fahrenheit temperatures are primary; dimensions and properties in SI units and the Celsius temperatures are shown as the approximate equivalents of the primary units and are presented only for information.

8.6 For direct U.S. Military procurement, purchase documents should specify not less than the following:

Title, number, and date of this specification
Form and size of product desired
Quantity of product desired
Level A packaging, if required (See 5.2.2).

8.7 Products meeting the requirements of this specification have been classified under Federal Supply Classification (FSC) 9535.

PREPARED UNDER THE JURISDICTION OF AMS COMMITTEE "G".

3.6 Quality:

The product, as received by purchaser, shall be uniform in quality and condition, sound, and free from "oil cans" (See 8.4) of depth in excess of the flatness tolerances, ripples, and foreign materials and from imperfections detrimental to usage of the product.

3.7 Tolerances:
(R)

Shall conform to all applicable requirements of AMS 2242 or MAM 2242.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection:
(R)

The vendor of the product shall supply all samples for vendor's tests and shall be responsible for performing all required tests. Purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the product conforms to the requirements of this specification.

4.2 Classification of Tests:

Tests for all technical requirements are acceptance tests and shall be performed on each heat or lot as applicable.

4.3 Sampling and Testing:
(R)

Shall be in accordance with the following; a lot shall be all product of the same nominal size from the same heat processed at the same time and in the same heat treatment batch.

4.3.1 Composition: One sample from each heat, except that for hydrogen determinations one sample from each lot obtained after thermal and chemical processing is completed.

4.3.2 Tensile Properties, Bending, Grain Size, and Surface Contamination:
(R) Not less than one sample from each lot.

4.3.2.1 Specimens for tensile tests of widths 9 inches (229 mm) and over shall be taken and tested in both the longitudinal and transverse directions; for widths under 9 inches (229 mm), specimens shall be taken in longitudinal direction.

4.3.2.2 For V-block or U-channel bend tests, specimen width shall be not less than 10 times the nominal thickness or 1 inch, (25 mm), whichever is greater. For free bend tests, minimum specimen width shall, when possible, be not less than 10 times the nominal thickness; maximum width need not be greater than 1 inch (25 mm).

## K. TARGET ENCLOSURE/VENT DESIGN AND CONDITIONS FOR ENTRY

### PROCEDURE FOR ACCESS TO THE E906 TARGET ENCLOSURE FOR INSTALLATION/REMOVAL OF COPPER FOIL, EXPANDER WORK, REPAIRING/REPLACING INSTRUMENTATION

The procedure for access to the E906 target enclosure for installation/removal of the copper foil is the same as that for the E866 experiment. Refer to pages 89-92 of the E866 target safety report, or pages 83-86 of the E906 Target Safety Report.

The list of personnel considered target experts consists of the following names:

Chiranjib Dutta

Wolfgang Lorenzon

Kazutaka Nakahara

Richard Raymond

Wang Su-Yin

Submitted by: D. Allspach Approved by: RD/MSD Department: James R. Kilmer

LH2 Target Safety Panel: Terry L. Ellerme
Verbal OK Tom Peterson

# PROCEDURE FOR ACCESS TO THE E866 TENT FOR INSTALLATION/REMOVAL OF COPPER FOIL

D. Allspach, J. Peifer / December 16, 1996

Only hydrogen target experts are allowed in the tent when a hydrogen or deuterium target is full in order to tune a refrigerator. For the purpose of tent entry, this is whenever either of a target's flask resistors read 80K or less. An operator or target expert must monitor the operation of the target systems looking for unexpected conditions during the execution of this procedure. In particular, the H2 detector must be checked in case of target leakage, status of the tent exhaust fan flow must be checked, the vent pressure of each target is to be monitored closely and proper helium flow and suction and discharge pressures must be verified. If the targets are running as expected, the task to tune a refrigerator may proceed with the condition that a hydrogen target expert perform the work inside the tent. Note that no one may enter the tent while the flammable gas detector is in alarm, nor during a power outage, nor if the tent exhaust fan is inoperable. The operator monitoring the systems must maintain communication with the expert inside the tent. If unexpected or unsafe conditions are observed during the tent access, the observation must be communicated to the person inside the tent. Communication will occur between an operator or another target expert who will enter the ME6 beamhall (but remain outside of the tent) in order to also meet controlled access requirements. This will occur via walkie-talkies. Note that the operator in the controls area must be outside of the control room when activating the walkie-talkie. No walkie-talkies may be taken into the tent. If trouble is communicated, the operation must be terminated and the tent must be vacated. No changes may be made at the target control rack during a tent access. The steps listed below must be adhered to.

## STEPS TO BE TAKEN WHEN INSTALLING/REMOVING THE FOIL

1. Make sure the magnet current is off for the ME6AN1 Magnet.
2. Before entering the tent, move the target system all the way to the east (this is the $LH_2$ Target position).
3. LOCK OUT the motion table power supply with a padlock.
4. Turn on the tent exhaust fan and leave fan controller switch in the manual-on position. TAG OUT this fan controller switch.
5. Carry no tools into the tent. Carry no nonessential objects into the tent such as pagers, tape measures, keys, etc.
6. Climb up the ladder on the west side of the SWIC.
7. Protect each target's upstream beam windows with a suitable material.
8. Install or remove copper foil on vacuum beam-pipe flange as required. The operator monitoring the target systems will warn of unexpected or unsafe target conditions. Before completing the job make sure no loose metal objects are left in the tent.
9. Remove the beam window protection from the targets.
10. Exit the tent, securing the flaps.
11. Unlock the motion mechanism.
12. Clear the tent area before trying to move the targets.
13. Check the motion mechanism for proper operation.
14. Untag the fan controller switch and set it to the automatic position.
15. Recharge the ME6AN1 magnet as required.

Note that for purposes of this procedure, the following personnel are considered target experts: Joe Davids, Mike McKenna and Jim Peifer. The operator must be made familiar with the current operating conditions of the target systems.

D. Allspach

LH$_2$ Target Safety Panel: W W Smart 9/30/96

# PROCEDURE FOR ACCESS TO THE E866 TENT FOR EXPANDER WORK

D. Allspach, J. Peifer / September 30, 1996

Only hydrogen target experts are allowed in the tent when a hydrogen or deuterium target is full in order to perform work on an expander. For the purpose of tent entry, this is whenever either of a target's flask resistors read 80K or less. An operator or target expert must monitor the operation of the target systems looking for unexpected conditions during the execution of this procedure. In particular, the H2 detector must be checked in case of target leakage, status of the tent exhaust fan flow must be checked, the vent pressure of each target is to be monitored closely and proper helium flow and suction and discharge pressures must be verified. If the targets are running as expected, the expander work may proceed with the condition that a hydrogen target expert perform the task. Note that no one may enter the tent while the flammable gas detector is in alarm, nor during a power outage, nor if the tent exhaust fan is inoperable. The operator monitoring the systems must maintain communication with the expert inside the tent. If unexpected or unsafe conditions are observed during the tent access, the observation must be communicated to the person(s) inside the tent. Communication from the person monitoring the system will be maintained with a second person entering the ME6 Beamhall (to also meet controlled access requirements) via walkie-talkies. Note that the operator in the controls area must be outside of the control room when activating the walkie-talkie. If two people are required inside the tent for the task, the second person must be a target expert. If only one person is required for the task, the second person may be a target expert or an operator and will remain just outside the tent maintaining communication with the expert inside the tent. If trouble is communicated, the operation must be terminated and the tent must be vacated. No changes may be made at the target control rack during a tent access. The steps listed below must be adhered to.

STEPS TO BE TAKEN WHEN WORKING ON AN EXPANDER

1. Make sure the magnet current is off for the ME6AN1 Magnet.
2. Before entering the tent, move the target system all the way to the east (this is the LH$_2$ Target position).
3. LOCK OUT the motion table power supply with a padlock.
4. Turn on the tent exhaust fan and leave fan controller switch in the manual-on position. TAG OUT this fan controller switch.
5. Only tools required for the expander work may be taken into the tent. Carry no nonessential objects into the tent such as pagers, tape measures, keys, etc.
6. Climb up the ladder on the west side of the SWIC.
7. Protect each target's upstream beam windows with a suitable material.
8. Perform required expander work. The operator monitoring the target systems will warn of unexpected or unsafe target conditions.
9. All tools must be accounted for when leaving tent. Before completing the job make sure no loose metal objects are left in the tent.
10. Remove the beam window protection from the targets.
11. Exit the tent, securing the flaps.
12. Unlock the motion mechanism.
13. Clear the tent area before trying to move the targets.
14. Check the motion mechanism for proper operation.
15. Untag the fan controller switch and set it to the automatic position.
16. Recharge the ME6AN1 magnet as required.

Note that for purposes of this procedure, the following personnel are considered target experts: Joe Davids, Mike McKenna and Jim Peifer. The operator must be made familiar with the current operating conditions of the target systems.

Submitted by: D. Allspach Approved by: RD/MSD Department: [signature]



LH2 Target Safety Panel: W. Smart 9/26/96

# PROCEDURE FOR ACCESS TO THE E866 TENT FOR REPAIRING/REPLACING INSTRUMENTATION

D. Allspach, J. Peifer / September 26, 1996

Only hydrogen target experts are allowed in the tent when a hydrogen or deuterium target is full in order to repair/replace instrumentation. For the purpose of tent entry, this is whenever either of a target's flask resistors read 80K or less. An operator or target expert must monitor the operation of the target systems looking for unexpected conditions during the execution of this procedure. In particular, the H2 detector must be checked in case of target leakage, status of the tent exhaust fan flow must be checked, the vent pressure of each target is to be monitored closely and proper helium flow and suction and discharge pressures must be verified. If the targets are running as expected, the task to repair/replace instrumentation may proceed with the condition that a hydrogen target expert perform the work inside the tent. Note that no one may enter the tent while the flammable gas detector is in alarm, nor during a power outage, nor if the tent exhaust fan is inoperable. The operator monitoring the systems must maintain communication with the expert inside the tent. If unexpected or unsafe conditions are observed during the tent access, the observation must be communicated to the person inside the tent. Communication will occur between an operator or another target expert who will enter the ME6 beamhall (but remain outside of the tent) in order to also meet controlled access requirements. This will occur via walkie-talkies. Note that the operator in the controls area must be outside of the control room when activating the walkie-talkie. If trouble is communicated, the operation must be terminated and the tent must be vacated. No changes may be made at the target control rack during a tent access. The steps listed below must be adhered to.

## STEPS TO BE TAKEN WHEN REPAIRING/REPLACING INSTRUMENTATION

1. Make sure the magnet current is off for the ME6AN1 Magnet.
2. Before entering the tent, move the target system all the way to the east (this is the $LH_2$ Target position).
3. LOCK OUT the motion table power supply with a padlock.
4. Turn on the tent exhaust fan and leave fan controller switch in the manual-on position. TAG OUT this fan controller switch.
5. Only tools required to repair/replace the instrumentation may be carried into the tent. Carry no nonessential objects into the tent such as pagers, tape measures, keys, etc.
6. Climb up the ladder on the west side of the SWIC.
7. Protect each target's upstream beam windows with a suitable material.
8. Perform required instrumentation repair/replacement. The operator monitoring the target systems will warn of unexpected or unsafe target conditions.
9. All tools must be accounted for when leaving tent. Before leaving the tent, make sure no loose metal objects are left inside the tent.
10. Remove the beam window protection from the targets.
11. Exit the tent, securing the flaps.
12. Unlock the motion mechanism.
13. Clear the tent area before trying to move the targets.
14. Check the motion mechanism for proper operation.
15. If re-entry into the tent is desired at this time, begin again at step 2 of this procedure and follow all steps except step 4. If no re-entry is desired, continue with step 16.
16. Untag the fan controller switch and set it to the automatic position.
17. Recharge the ME6AN1 magnet as required.

Note that for purposes of this procedure, the following personnel are considered target experts: Joe Davids, Mike McKenna and Jim Peifer. The operator must be made familiar with the current operating conditions of the target systems.

Submitted by: D. Allspach Approved by: RD/MSD Department: R L Ulmer 7-26-96

LH$_2$ Target Safety Panel: N. M. Swart 7/26/96

# PROCEDURE FOR ACCESS TO THE E866 TENT FOR REFRIGERATOR TUNING

D. Allspach, J. Peifer / July 25, 1996

Only hydrogen target experts are allowed in the tent when a hydrogen or deuterium target is full in order to tune a refrigerator. For the purpose of tent entry, this is whenever either of a target's flask resistors read 80K or less. An operator or target expert must monitor the operation of the target systems looking for unexpected conditions during the execution of this procedure. In particular, the H2 detector must be checked in case of target leakage, status of the tent exhaust fan flow must be checked, the vent pressure of each target is to be monitored closely and proper helium flow and suction and discharge pressures must be verified. If the targets are running as expected, the task to tune a refrigerator may proceed with the condition that a hydrogen target expert perform the work inside the tent. Note that no one may enter the tent while the flammable gas detector is in alarm, nor during a power outage, nor if the tent exhaust fan is inoperable. The operator monitoring the systems must maintain communication with the expert inside the tent. If unexpected or unsafe conditions are observed during the tent access, the observation must be communicated to the person inside the tent. Communication will occur between an operator or another target expert who will enter the ME6 beamhall (but remain outside of the tent) in order to also meet controlled access requirements. This will occur via walkie-talkies. Note that the operator in the controls area must be outside of the control room when activating the walkie-talkie. No walkie-talkies may be taken into the tent. If trouble is communicated, the operation must be terminated and the tent must be vacated. No changes may be made at the target control rack during a tent access. The steps listed below must be adhered to.

## STEPS TO BE TAKEN WHEN TUNING A REFRIGERATOR

1. Make sure the magnet current is off for the ME6AN1 Magnet.
2. Before entering the tent, move the target system all the way to the east (this is the LH$_2$ Target position).
3. LOCK OUT the motion table power supply with a padlock.
4. Turn on the tent exhaust fan and leave fan controller switch in the manual-on position. TAG OUT this fan controller switch.
5. Carry no tools into the tent. Carry no nonessential objects into the tent such as pagers, tape measures, keys, etc.
6. Climb up the ladder on the west side of the SWIC.
7. Protect each target's upstream beam windows with a suitable material.
8. Perform refrigerator tuning. The operator monitoring the target systems will warn of unexpected or unsafe target conditions. Before completing the job make sure no loose metal objects are left in the tent.
9. Remove the beam window protection from the targets.
10. Exit the tent, securing the flaps.
11. Unlock the motion mechanism.
12. Clear the tent area before trying to move the targets.
13. Check the motion mechanism for proper operation.
14. Untag the fan controller switch and set it to the automatic position.
15. Recharge the ME6AN1 magnet as required.

Note that for purposes of this procedure, the following personnel are considered target experts: Joe Davids, Mike McKenna and Jim Peifer. The operator must be made familiar with the current operating conditions of the target systems.

## E906 Proposal to Vent Hydrogen Gas into the SeaQuest Hall in NM4

The E906 collaboration proposes that hydrogen and deuterium gases from the E906 liquid targets be vented into the SeaQuest Hall in Building NM4 instead of being vented to outside, as is the usual practice. This document includes the following:

- Description of the proposed vent location, and radius calculation to maintain lower explosive limit (4%) for uniformly mixed hydrogen.
- Distances and flammable gas concentration at possible ignition sources.
- Details of tent venting calculations
- Description of the curtain upstream of the target.

A drawing of the proposed system is shown in Fig.K1. A 10-inch diameter ducting would carry gas to an outlet located above the beam axis, 10 ft above the ceiling of the target enclosure, 3 ft downstream of the upstream end of the beam dump, and above the top-most shielding blocks.
Each of the two liquid targets contains 2.2 liters of liquid. This is equivalent to 0.15 kg of hydrogen, and 0.185 kg hydrogen equivalent mass of deuterium. These 4.4 liters of liquid are equivalent to about 4000 liters (140 $\mathrm{ft}^3$) of gas at STP. If mixed in air uniformly, a concentration of 4% which is the lower explosive limit, would occupy a volume of 100 $\mathrm{m}^3$. A hemisphere of this volume has a radius of about 3.6 m ($\sim$ 12 ft).
In the SeaQuest Hall, the closest ignition sources are the high voltage connections on Station 1 detectors. These connections are about 19 ft from the proposed vent outlet. At that distance, the concentration would be 1.0%, according to the calculation that the hemispherical volume is $\frac{2}{3}\pi(19\mathrm{ft})^3 = 14000\mathrm{ft}^3$, and thus the concentration is 140 $\mathrm{ft}^3$/hemispherical volume = 1.0%. In addition there are other possible ignition sources which are summarized below:

| Sources | Distance from the vent (ft) | Hydrogen concentration (hemispherical approx.) | Height from the ground (ft) |
|---|---|---|---|
| HV connection (station 1) | 19 | 1.00% | 14 |
| Heaters on vertical walls above FMAG | 23 | 0.55% | 33 |
| Access control and signal circuit' Beam right (between NM3 and NM4) | 23 | 0.57% | 8 |
| Crane motor | 23 | 0.53% | 45 |

Note that the ceiling is 52 ft, and the exhaust vent is 24 ft from the ground. The NM4 hall volume is 313,000 ft$^3$.
Assuming that the vented gas rises toward the ceiling of the hall and distributes itself homogeneously under the ceiling, we estimate that for a gas concentration equivalent to the 4% explosive limit, the gas will need to occupy a 0.58 ft layer below the ceiling, as the following calculation shows:

- explosive limit = 4%
- area of ceiling = 43 ft × 140 ft (width×length) = 6020 ft$^2$
- thickness of layer $= \frac{\text{volume}}{\text{explosive limit} \times \text{area of ceiling}} = \frac{140\text{ft}^3}{0.04 \times 6020\text{ft}^2} = 0.58$ ft

Since all known ignition sources are well below the bottom edge of this layer, this poses no explosive risk. It is important to point out that the $H_2/D_2$/air mixture will not stay like a gas bubble under the ceiling of the hall, but rather diffuse to eventually occupy the entire NM4 hall volume, ending up at concentration levels far below any chance for explosion. The gas will then be exchanged with the rest of the air from the hall to the outside.

## E906 Target Tent (Enclosure) and Ventilation calculation

The calculations are based on the fact that the liquid from the flask evaporates inside the target vacuum volume and is then vented through the vacuum system parallel plate relief devices as cold vapor. Most of the numbers in the calculations are very standard and the same procedure followed by E866 has been adopted as far as practicable.

**Estimation of venting time:**

Here it is assumed that it is highly improbable that both the independent target systems would fail simultaneously. Hence, the timing estimation is determined for only one target failure. The relevant quantities are :

- $M_{H_2}$ = mass content of hydrogen in the target = 163 g
- $M_{D_2}$ = mass content of deuterium in the target = 398 g
- $V_{H_2}$ = Volume of discharged $H_2$ from rupture at 70° = 70 $ft^3$
- $V_{D_2}$ = Volume of discharged $D_2$ from rupture at 70° = 85 $ft^3$
- $V_{encl}$ = Volume of the target enclosure = 129in × 76in × 108in = 612.7 $ft^3$
- $T_{H_2}$ = Time required to relieve hydrogen = $\frac{M_{H_2}}{m_{H_2}}$ = 4.16 s
- $T_{D_2}$ = Time required to relieve deuterium = $\frac{M_{D_2}}{m_{D_2}}$ = 7.32 s

With a fan with a capability of 1300 cfm, one can deduce the time required by the fan to vent the different contamination as follows:

$$t_{H_2} = \frac{V_{H_2}}{1300} = 3.2s, \tag{0.0.1}$$
$$t_{D_2} = \frac{V_{D_2}}{1300} = 3.9s, \tag{0.0.2}$$
$$t_{encl} = \frac{V_{encl}}{1300} = 28s, \tag{0.0.3}$$

where $t_{H_2/D_2/encl}$ is the time required to vent ($H_2$/$D_2$/air) once the fan is turned on at $t = 0$ s. By comparing the time required to relieve $H_2$ or $D_2$ through a target parallel plate relief in case of a flask rupture (4.16 s and 7.32 s, respectively) to the time required to vent the equivalent room temperature volume of $H_2$ or $D_2$ with the fan (3.2 s and 3.9 s, respectively), it is seen that a ventilation capacity of 1300 cfm is more than adequate.

**Pressure Drop Across the Enclosure Ventilation Ducting:**

The ducting of the proposed ventilation system consists of ∼12 ft of 10 inch diameter commercial steel piping with one regular 45° elbow.
The following relevant quant ities are used in the calculations :

- $L$ = Length of the pipe = 12 ft
- $D$ = Diameter of the pipe = 0.833 ft
- $K$ = Resistance coefficient for regular 90° elbow = 0.15
- $f$ = Friction factor from Moody diagram = 0.0175
- $(L_e)_1$ = Effective length for 90° elbow = $\frac{KD}{f}$ = 7.14 ft
- $(L_e)_2$ = Effective length for 45° elbow = $0.57\times(L_e)_1$ = 4.1 ft

- $g$ = acceleration due to gravity = 32.2 ft/s$^2$
- $z$ = Elevation change = 10 ft
- $\rho_{H_2}$ = Density of hydrogen at 70° F = 0.08233 kg/m$^3$
- $\rho_{D_2}$ = Density of deuterium at 70° F = 0.1645 kg/m$^3$
- $m_{H_2}$ = Mass flow rate of hydrogen through parallel plate relief = 0.0392 kg/s
- $m_{D_2}$ = Mass flow rate of deuterium through parallel plate relief = 0.0544 kg/s
- $F_{H_2}$ = Volumetric flow rate of hydrogen = $\frac{m_{H_2}}{\rho_{H_2}}$ = 1009 cfm
- $F_{D_2}$ = Volumetric flow rate of deuterium = $\frac{m_{D_2}}{\rho_{D_2}}$ = 702 cfm
- $V$ = Fluid velocity in the pipe = $\frac{Q}{\pi(\frac{D}{2})^2}$ = 31 ft/s for $H_2$ ($H_2$ yields the highest velocity)

Now following the procedure adopted by E866, we will use the air density $\rho_{air} = 0.072$ lb/ft$^3$ at STP to calculate the maximum possible pressure drop across the system. The pressure drop is given by:

$$\Delta P = \left[ f \left( \frac{L + (L_e)_2}{D} \right) \cdot \frac{V^2}{2} + gz \right] \cdot \rho_{air} \tag{0.0.4}$$

Now putting all the respective values, we obtain $\Delta P = 0.21$ inches of $H_2O$. This is the highest positive pressure the target enclosure would see in case of a target flask rupture when the fan is not turned on. The fan will be chosen to provide a 1300 cfm flow through the vent duct.

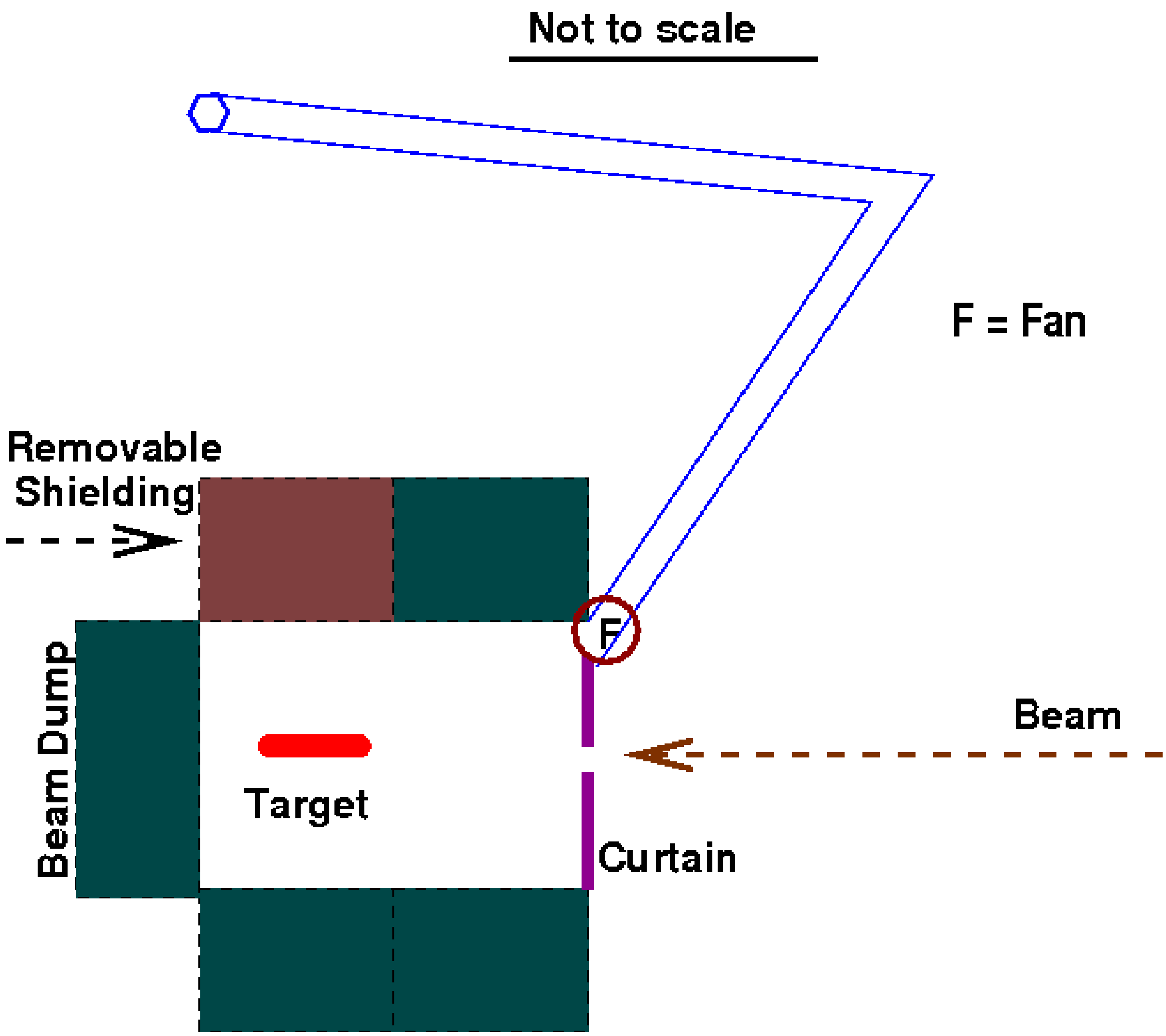



Figure K1: Rough schematic of the target vent ducting (not to scale). The fan position is flexible and can be mounted according to different other requirements (available space, support convenience etc.). The mounting details are not presented at this point. The various dimensions are already discussed in the text. The fan will be chosen and mounted in such a way to provide 1300 cfm flow through the vent duct.

## Curtain Design

We propose use of a *strip door* as the curtain upstream of the E906 target. These doors consist of set of vertical transparent vinyl strips, overlapping and suspended from the top. Such doors are in wide commercial use. Going through a door requires pushing apart adjacent strips. When the strips are released the gap closes. For the E906 target enclosure these doors, being transparent, would make search of the area easier and would allow light from outside into the enclosure. Also, construction and mounting of a solid door would not be neccessary.

The enclosure is shown schematically in Fig.K2, looking downstream toward the targets.

12 inch wide strips are drawn, with overlaps of 2 inches on each side. The strips would generally hang to within 1 foot of the floor, other than on the left side of the enclosure. There the strips would stop at 4 feet from the floor to allow higher airflow through the gap between the enclosure floor blocks and the side blocks. Near the center the tent vent van is near the roof of the enclosure and a beam pipe is centered 2 feet above the floor blocks. In this area a solid sheet would be used instead of the curtain.

# CONDITIONS FOR ACCESS TO THE SEAQUEST HALL

The conditions for access to the SeaQuest Hall are the same as those for the ME6 Hall for E866. Refer to page 93 of the E866 target safety report, or page 94 of the E906 Target Safety Report.

# CONDITIONS FOR ACCESS TO THE ME6 BEAMHALL

D. Allspach, J. Peifer
July 25, 1996

(1) Note that the ME6 BeamHall will remain interlocked (controlled access required) whenever there is liquid in either of the hydrogen or deuterium targets. For these purposes, this is whenever either of a target's flask resistors read 80K or less.

(2) Flashing Blue light indicates hydrogen and/or deuterium is present inside the target flasks. This is a normal running condition.

(3) A whooper is located inside the beamhall. An alarm from the whooper indicates hydrogen or deuterium is detected by the flammable gas detector. The ME6 beamhall must be vacated immediately if the whooper is in alarm. The Operations Center and FIRUS are contacted automatically when an alarm occurs.

(4) **No unauthorized personnel are allowed inside the Target Tent.** Only Liquid Hydogen Target Experts are allowed to enter the tent with an approved access procedure.

(5) An ODH fan is installed to constantly ventilate the ME6 beamhall in the area of the Target Tent. The ODH fan maintains an ODH Class Zero in the beamhall. Before access is granted to the ME6 beamhall, normal operation of the ODH Fan Flow must be verified. If the ODH Fan Flow status is OK, no other special precautions are required. If the ODH Fan Flow is in alarm, access may still be granted, but ODH Class 1 rules must be followed.

## L. PERFORMANCE TESTS

### PERFORMANCE TESTS

Pressure test, relief valve test, stainless steel flask joint test, flask pressure testing, titanium window testing, pneumatic vent valve leak test were all performed prior to the E866 experiment, and all of the above items will be re-used for the E906 target.

# Pressure Piping Test

This section defines procedures for designing, fabricating and testing pressure piping systems.

**SCOPE**

This chapter includes all piping systems that fall under the following subsystems:

1. Target internal piping.
2. Target external existing piping.
3. Target external new piping.

**Target Internal Piping**

- All piping within the target vacuum jacket, including the condenser and the supply and relief pipes, will be pressure tested to 1.25 times the maximum allowable working pressure according to UG-100 of the ASME Boiler and Pressure Vessel Code, Section VIII Div.1 (hereafter called the Code).

**Target External Existing Piping**

Piping from the hydrogen, deuterium, and nitrogen cylinders to the target will make use of partially existing piping between the gas cylinders and the experimental hall.

- Existing piping will be pneumatically tested to 90% of the relief pressure.
- No piping or system components with relief settings above 150 psig exist. Thus, Chapter 5034 of the Fermilab ES&H Manual does not apply.
- A leak test using suitable means shall also be performed prior to operating the system.

**Target External New Piping**

- New external piping between the gas cylinders and the target will be tested to 1.1 times the relief pressure.
- Material certification and engineering notes for all joints, fittings, and piping will be documented on the "FESHM 5031.1 Piping Engineering Notes".
- There will be no welded joints in external piping.
- A leak test using suitable means shall also be performed prior to operating the system.

## E906 STAINLESS STEEL FLASK JOINT TESTING

The E906 target system will initially re-use the E866 target flask. Flask joint tests were performed for the E866 target system. Refer to pages 133-139 of the E866 target safety report, or pages 98-104 of the E906 Target Safety Report.

New flasks are being fabricated as spares. Before installation, new joint tests will be performed. Results of the test will be submitted to the Target Safety Committee for approval.

# E866 STAINLESS STEEL FLASK JOINT TESTING

D. Allspach
October 11, 1995

## *Introduction:*

A series of tests were completed to evaluate the strength of overlapped soft soldered joints for stainless steel 0.002 inch and 0.003 inch thick material. The testing consisted of performing tensile tests on several samples following Appendix II of the LH2 Target Guidelines. The difference in our testing was the use of stainless steel samples which had overlapped soft soldered joints at the center of the test sample.

Several samples were made with variation in overlap width, soldering methods and comparison of the flux which has been on the shelf since the past fixed target run to some newly purchased flux (same type). Some samples without a joint were tested as well in order to establish some reference data. Also, a calculation was performed to predict how great of a shear stress we should expect the joint to withstand before failing. For a 0.5 inch overlapped joint, the result is a value higher than the strength of the stainless steel. We thus expect that the samples will fail at a stress greater than or equal to the allowable stress of the stainless steel (18,800 psi) times four (= 75,200 psi) , which is the ASME code estimated ultimate stress of the stainless steel material.

## *Summary of test results:*

Testing summary below includes overlapped joint samples which were produced with 60/40 solder and MA stainless steel flux from Lake Chemical Co., Chicago, IL as recommended in the Target Guidelines. Joints were made using a soldering iron as is done in the production of target flasks.

### *0.002 inch thick stainless steel test samples*

Average tensile strength of five samples without a joint = 93,000 psi
Tensile strength of strongest sample without a joint = 95,800 psi
Tensile strength of weakest sample without a joint = 86,600 psi

Average tensile strength of five samples with a 0.5" joint = 98,300 psi
Tensile strength of strongest sample with a 0.5" joint = 104,800 psi
Tensile strength of weakest sample with a 0.5" joint = 93,800 psi

*0.003 inch thick stainless steel test samples*

Average tensile strength of three samples without a joint = 93,000 psi
Tensile strength of strongest sample without a joint = 94,100 psi
Tensile strength of weakest sample without a joint = 91,600 psi

Average tensile strength of five samples with a 0.5" joint = 90,200 psi
Tensile strength of strongest sample with a 0.5" joint = 91,800 psi
Tensile strength of weakest sample with a 0.5" joint = 88,900 psi

***Discussion:***

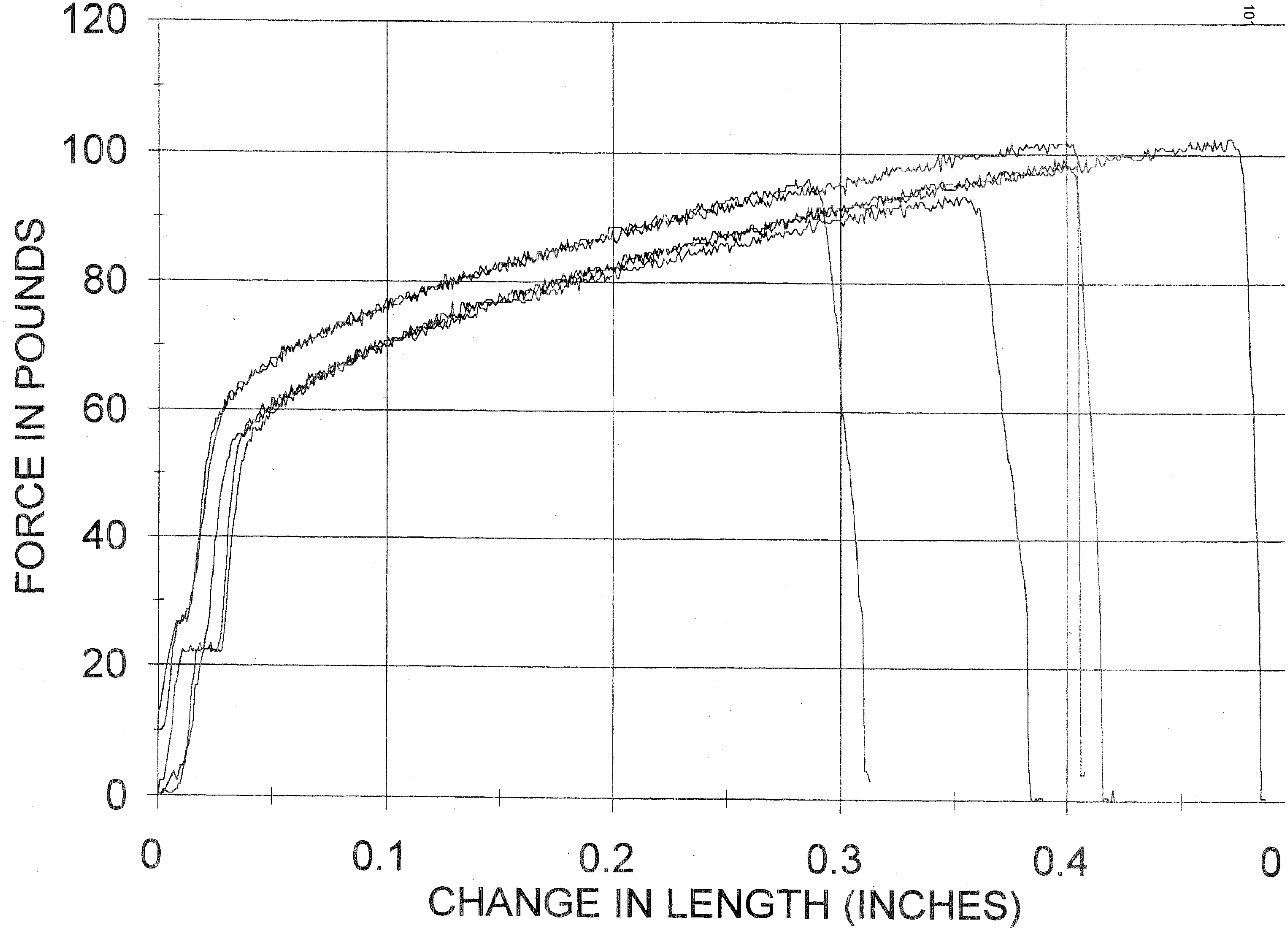
Attached, please find the tensile test data of the 0.002 inch and 0.003 inch samples (with and without a joint). In most cases, the failure occurred in the base material rather than in the joint. In all cases, the failure occurred at a stress clearly exceeding 75,200 psi. Thus, the test results indicate that using 0.5 inch overlapped joints in the target flasks will not de-rate their expected strength. Using 0.5 inch overlapped joints, we have consistently produced solder joints with a strength exceeding the material strength assumed (18,800 psi x safety factor of 4) in the flask design calculations. A joint efficiency equal to one (1) is thus valid in the flask stress design calculations.

# E866 Flask Materi. Tensile Test Results

| Sample # | Width (inches) | Cross Section (sq. in.) | Break Point (pounds) | Tensile (psi) | Break Type |
|---|---|---|---|---|---|
| | Test A - 1/2" overlap of 0.002" thick T304 Annealed Stainless Steel | | | | |
| 1 | 0.494 | 0.000988 | 103.6 | 104858 | base mat'l at edge of overlap |
| 2 | 0.516 | 0.001032 | 103 | 99806 | base mat'l away from joint |
| 3 | 0.506 | 0.001012 | 99.7 | 98518 | base mat'l away from joint |
| 4 | 0.495 | 0.00099 | 93.6 | 94545 | base mat'l away from joint |
| 5 | 0.512 | 0.001024 | 96.1 | 93848 | base mat'l away from joint |
| | Test B - One piece sample of 0.002" thick T304 Annealed Stainless Steel | | | | |
| 6 | 0.506 | 0.001012 | 95.1 | 93972 | |
| 7 | 0.501 | 0.001002 | 93.6 | 93413 | |
| 8 | 0.505 | 0.00101 | 96.5 | 95545 | |
| 9 | 0.508 | 0.001016 | 88 | 86614 | |
| 10 | 0.518 | 0.001036 | 99.3 | 95849 | |
| | Test E - One piece sample of 0.003" thick T304 Annealed Stainless Steel | | | | |
| 21 | 0.48 | 0.00144 | 135.6 | 94167 | |
| 22 | 0.491 | 0.001473 | 137.5 | 93347 | |
| 23 | 0.481 | 0.001443 | 132.3 | 91684 | |
| | Test I - 1/2" overlap of 0.003" thick T304 Annealed Stainless Steel | | | | |
| 39 | 0.504 | 0.001512 | 139 | 91813 | base mat'l away from joint |
| 40 | 0.51 | 0.00153 | 136 | 88934 | base mat'l away from joint |
| 41 | 0.506 | 0.001518 | 136 | 89869 | joint seam |
| 42 | 0.51 | 0.00153 | 138 | 90350 | joint seam |
| 43 | 0.508 | 0.001524 | 137 | 90053 | base mat'l at edge of overlap |

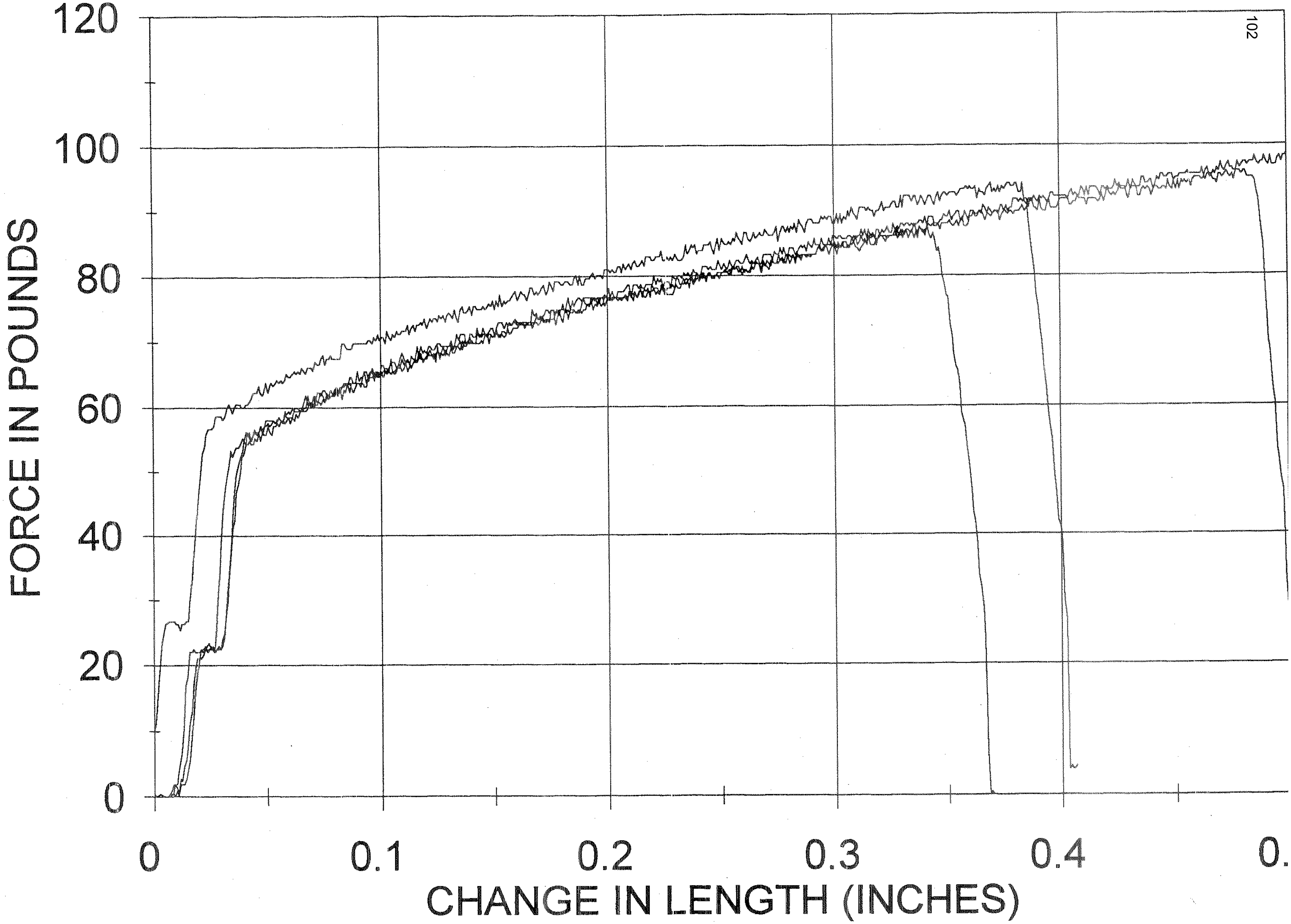
# TEST A OVERLAP SOLDERED W/ IRON

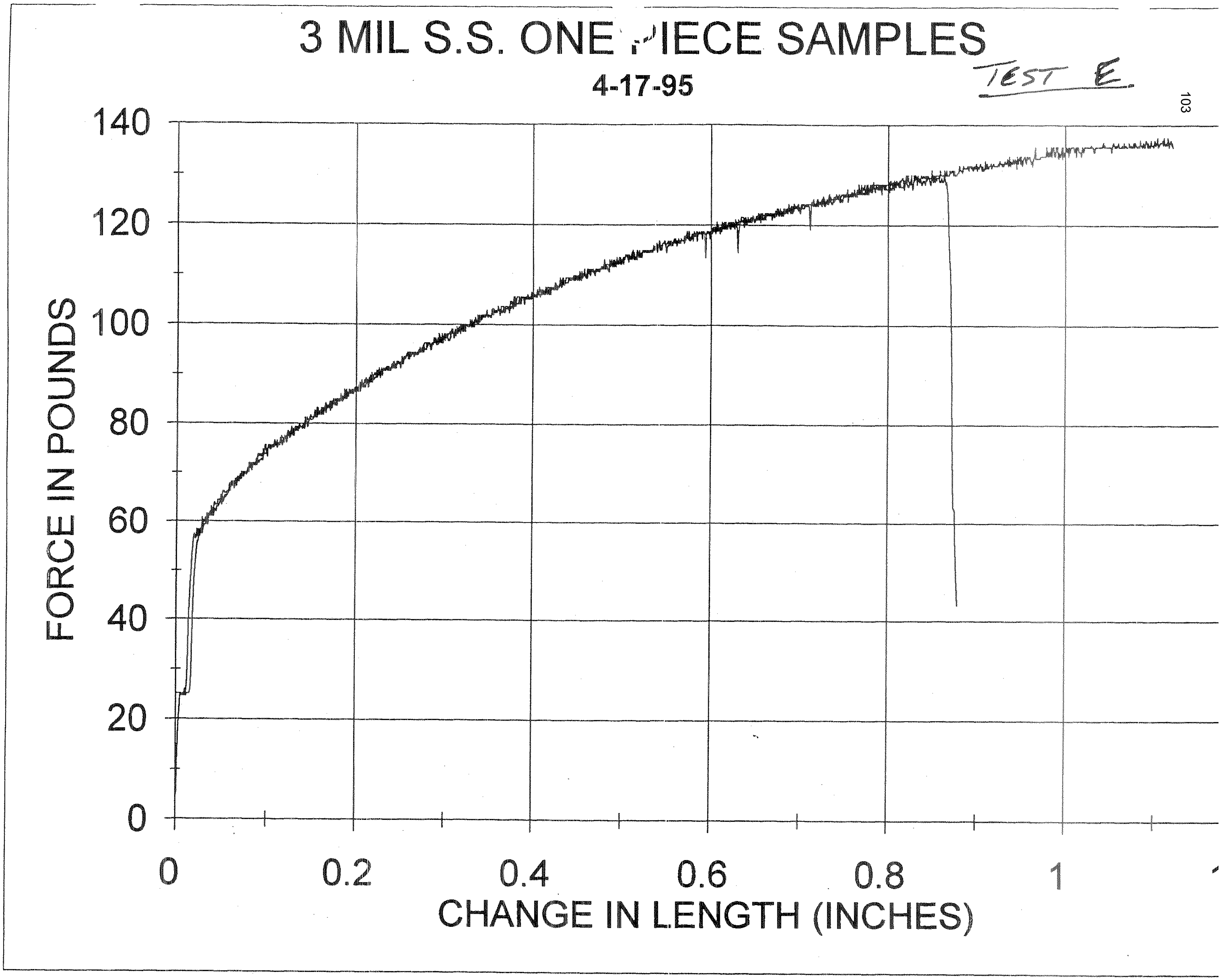
**4-12-95**



# TEST B ONE PIECE SAMPLE

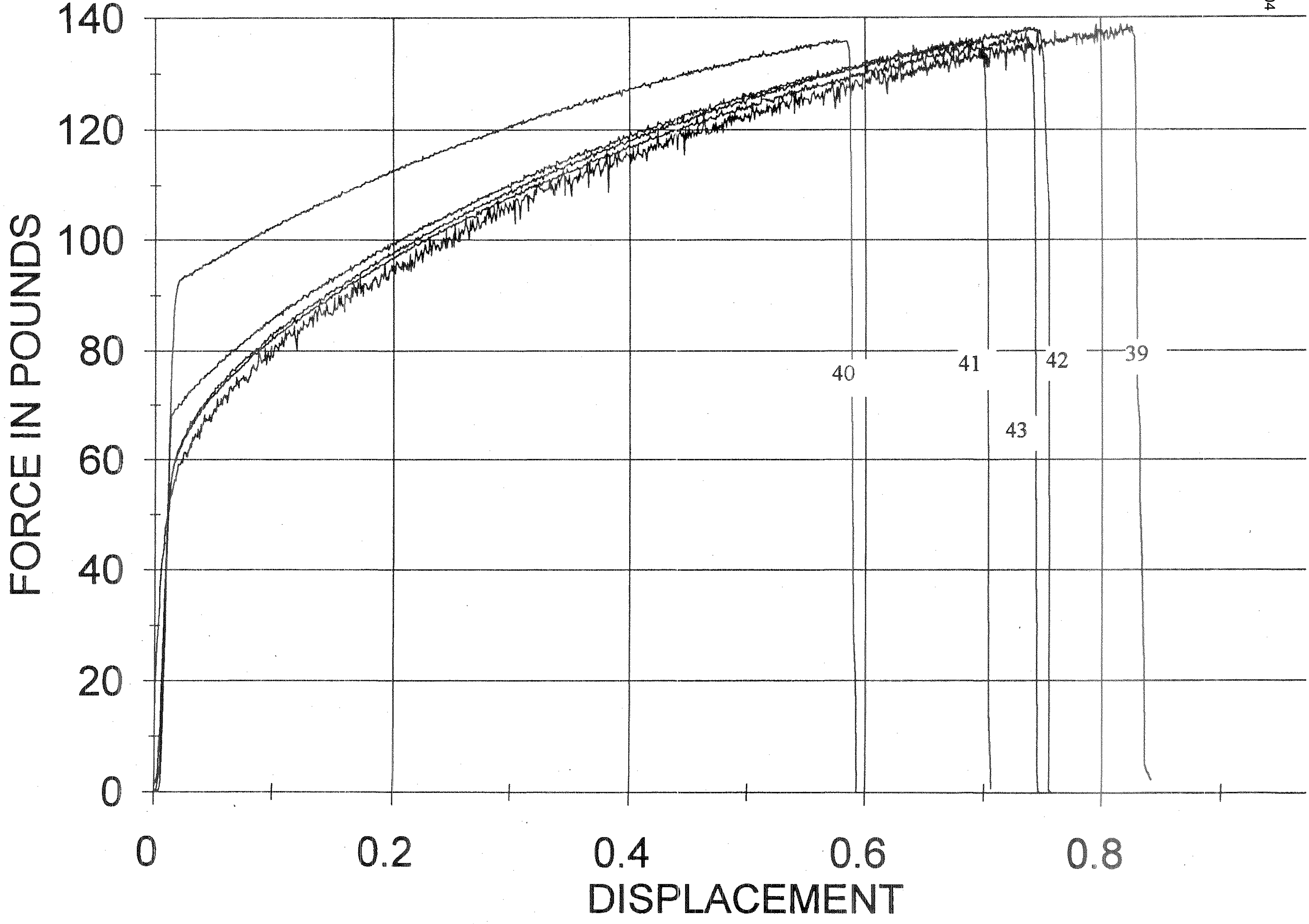
**4-12-95**




3 MIL S.S. ONE PIECE SAMPLES
4-17-95
TEST E
FORCE IN POUNDS
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
CHANGE IN LENGTH (INCHES)

# TEST I - .5" OVERL.,P (IRON & NEW FLUX)

07/26/95



# FLASK PRESSURE TESTING

The E906 target system will initially re-use the E866 target flask. Flask pressure tests were performed for the E866 target system. Refer to pages 140-143 of the E866 target safety report, or pages 106-109 of the E906 Target Safety Report.

New flasks are being fabricated as spares. Before installation, new pressure tests will be performed. Results of the test will be submitted to the Target Safety Committee for approval.

# Flask Pressure Testing Results

November 30, 1995
D. Allspach

Flask testing was performed at Lab 3 in accordance with the Target Guidelines Flask Testing procedures (Section II.C.3.). Excerpts recorded in the E866 Hydrogen Target Log Book by Mike McKenna are copied below for your reference. Three types of tests were completed:

(1) Liquid Nitrogen Pressure Test to 1.5 times the MAWP.

(2) Hydrostatic Burst Test.

(3) Pneumatic Tests to 1.25 times the MAWP.

(1) Log Book Notes: "This prototype flask (which was an inferior sample and had several material flaws) was, non-the-less, used for testing. The first test was a LN2 pressure test. See set up schematic and photos. The flask was filled about 2/3 with LN2 then pressurized to 40 psi and allowed to sit for several minutes. No adverse affects were seen."

The schematic is shown in Diagram 1 and the photos taken in this test are photos #1 and #2.

(2) Log Book Notes: "This same prototype flask was then tested hydrostatically to failure. Yield occurred at around 130 psi with ultimate failure at 143 psi."

The working schematic is shown in Diagram 2 and photo #3 shows the flask under pressure.

(3) Other than the prototype flask, five flasks were constructed for the E866 experiment. Three for planned use, leaving two spares. A room temperature pneumatic test was completed for each of the five. The testing was successful.

Log Book Notes: "Each flask was pressurized to 31 psi (1.25 x MAWP) and leak checked using the LEAK HUNTER."

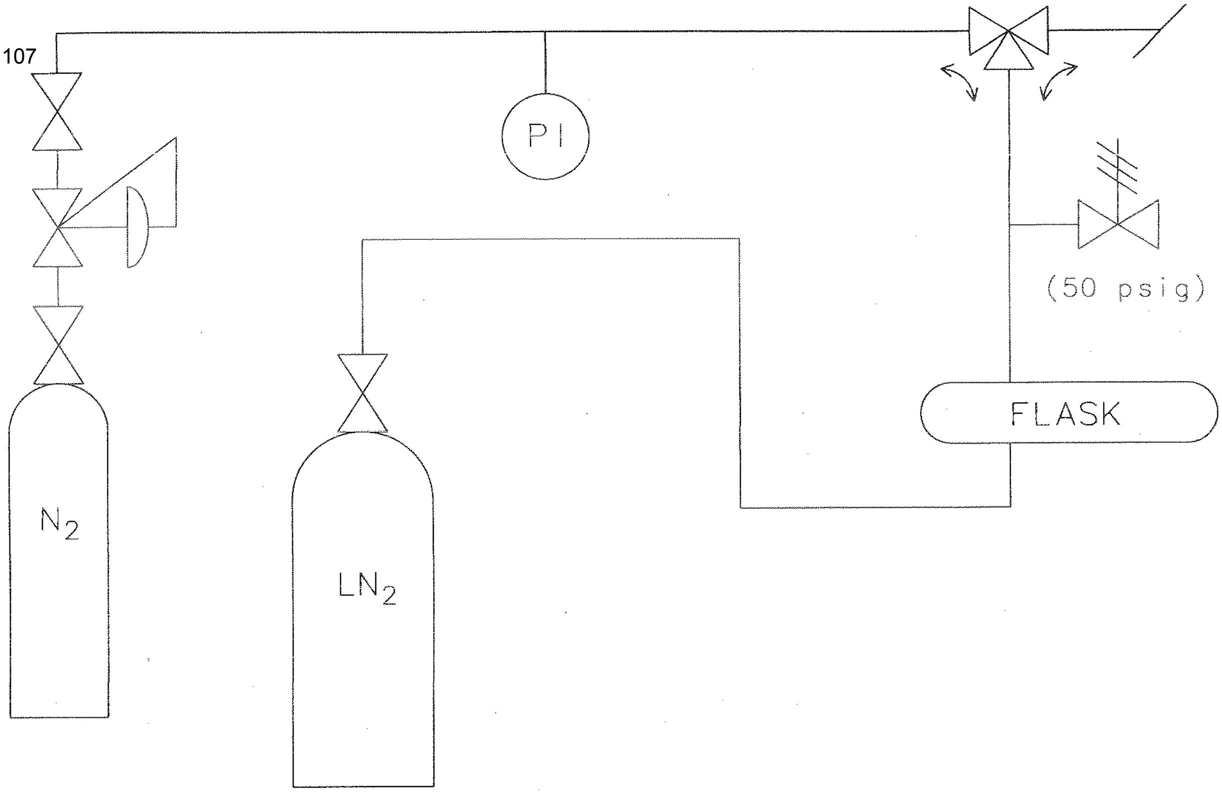



Diagram 1. $LN_2$ Pressure Test

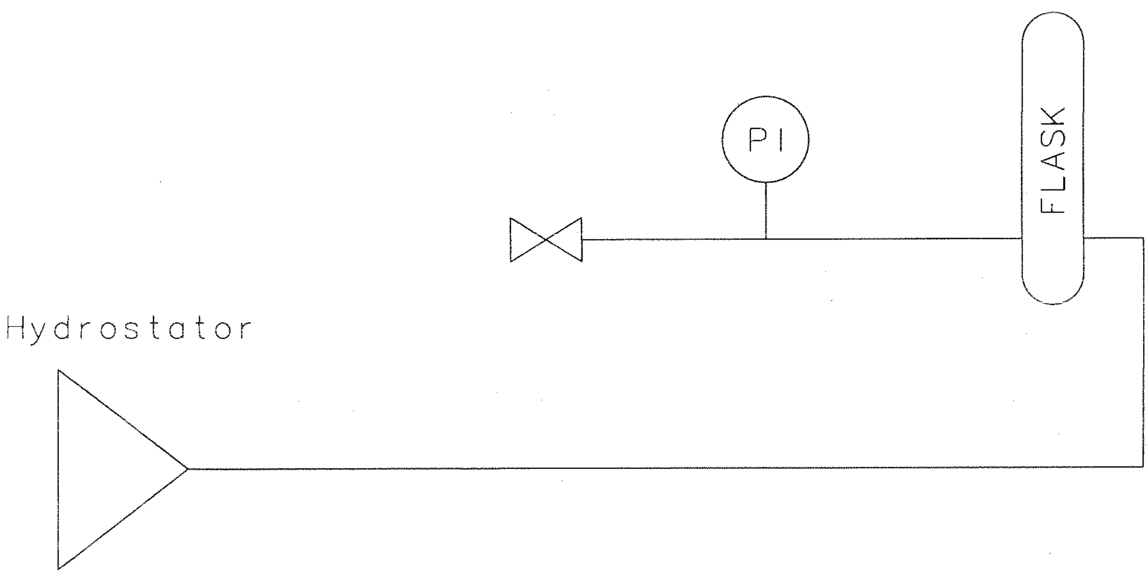



Diagram 2. Hydrostatic Burst Test

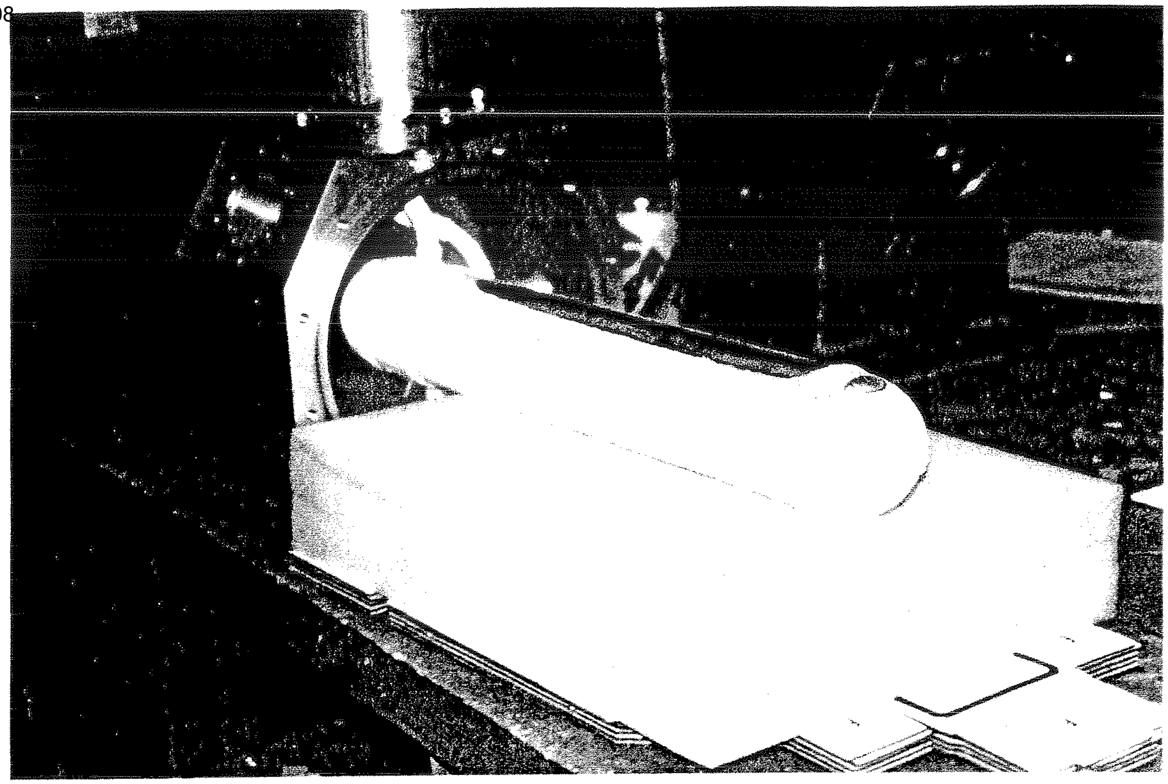


Photo # 1: LN2 Pressure Test

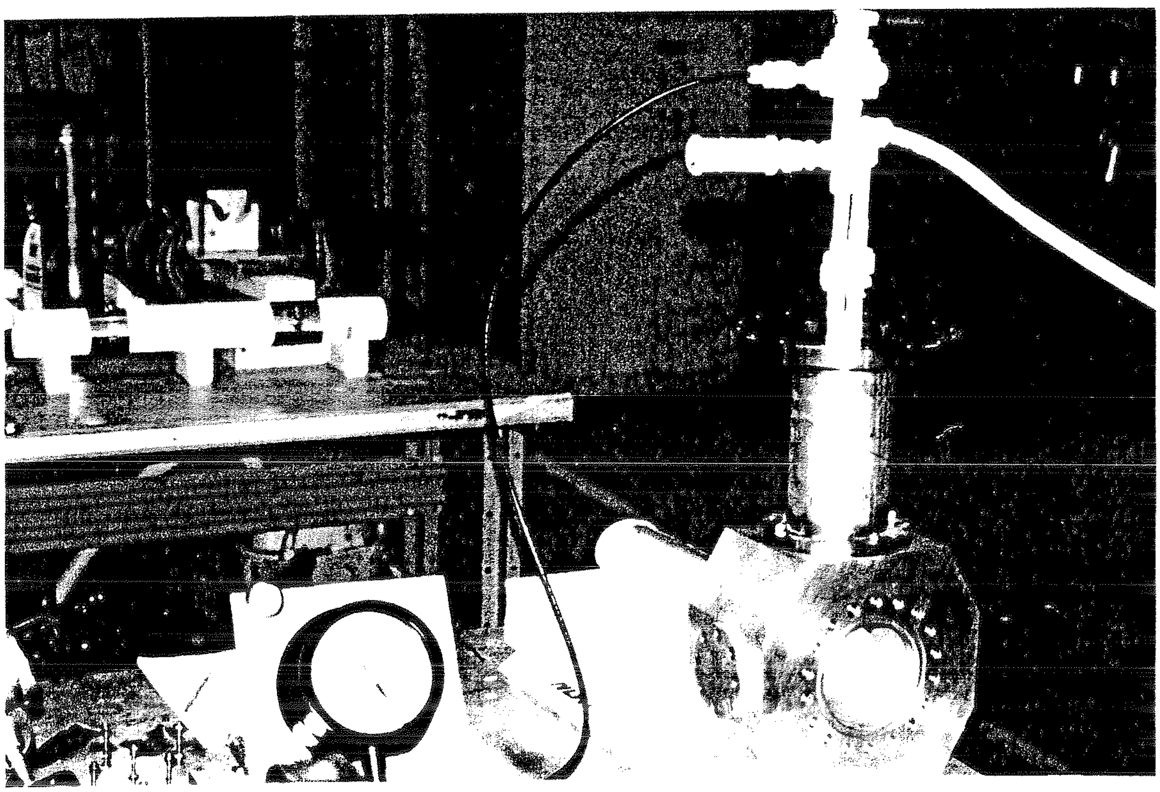


Photo # 2: LN2 Pressure Test

*Photo # 3: Hydrostatic Burst Test*

## TITANIUM WINDOW TESTING

New titanium windows will be fabricated for the E906 target system. The design of the windows will be identical to those of the E866 Target System. Refer to page 151 of the E866 target safety report, or page 111 of the E906 Target Safety Report. Material Certification of the titanium windows will be submitted to the Target Safety Committee for approval.

# Titanium Window Testing

January 30, 1995 / D. Allspach, J. Peifer

The following tests will be conducted to verify the results of the titanium window stress calculations. Please reference "Titanium Window Stress" calculations for E866. Test data will be logged and the results documented and included in the E866 Target Safety Report.

(1) As the MAWP of the vacuum container is equal to 15 psid internal, the windows will be tested as a part of the general vacuum system pressure testing. During this test the windows are required to sustain 22.5 psid.

(2) Five sample windows will be tested to determine their burst pressure. This test will be conducted at room temperature and will show the window burst pressure to be consistently greater than or equal to 37.5 psid.

(3) Five sample windows will be tested to determine their burst pressure at cryogenic conditions. The windows are to be pressurized while cooled with liquid nitrogen. The pressure differential will be slowly increased showing the window burst pressure to be consistently greater than or equal to 37.5 psid at cryo conditions.

(4) Five tests, each with two sample windows, will occur in which an amount of liquid nitrogen (determined as equivalent to the volume of liquid $H_2/D_2$ in an E866 flask, based on the expansion ratio from the saturated liquid to the saturated vapor state) will be released into the target flask vacuum container. The container will be under vacuum immediately prior to release of the liquid nitrogen. The test is to show that each window will survive a simulated flask failure.

Notes:

(a) Material to be tested shall be Titanium alloy, Ti 15-3, with a material thickness equal to 0.0055 inches. A manufacturer's material certification sheet showing composition, yield strength and ultimate strength of the titanium shall be obtained.

(b) The flange and mating surface which hold the window samples during testing are to be fabricated as specified for the actual E866 liquid targets.

(c) See "E866 Vacuum Jacket Relief" calculations which show the maximum internal pressure of the vacuum container in the case of a flask failure to be 3.5 psid.

## PNEUMATIC VENT VALVE TESTING

New pneumatic vent valves will be installed for the E906 Target system. The testing procedure will be identical to that used for the E866 Target pneumatic vent valves. For procedures, refer to pages 152-153 of the E866 target safety report, or pages 113-114 of the E906 target safety report.

# Pneumatic Vent Valve Leak Testing

J. Brusoe / June 6, 1995
Revised: 10-19-95

The vent valve labeled PV-03-H on the E-866 P&I Diagram was leak tested at both room temperature and after being cooled with liquid nitrogen. The attached pages include photographs of the test in progress as well as a diagram of the testing setup. The testing procedure is described below. The results are summarized in the following table:

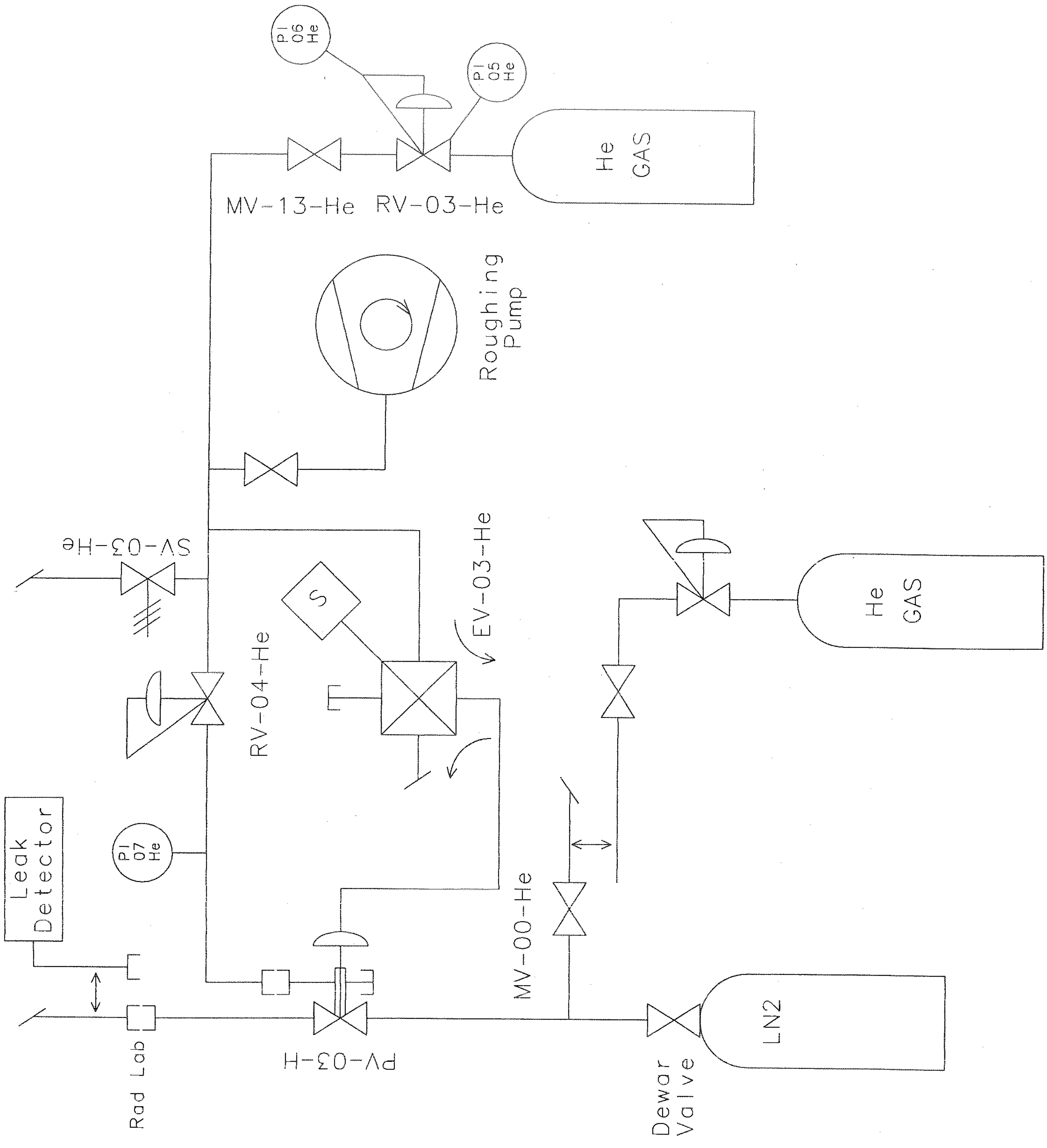
## Leak Testing Results

| Test Description | Vacuum Pressure |
|---|---|
| Room Temp. Test | 2.5 x $10^{-9}$ Torr |
| 1st Cold Test | 9.9 x $10^{-9}$ Torr |
| 2nd Cold Test | 1.7 x $10^{-9}$ Torr |
| 3rd Cold Test | 1.2 x $10^{-9}$ Torr |

It is believed that the gradually improving results were from the valve and testing setup cleaning itself from successive exposures to vacuum, eventually leading to lower outgassing and thus a better vacuum.

## Testing Procedure

1. Purge the valve sleeve by flowing He through it for several minutes, then recap it.
2. Open PV-03-H, the vent valve that is being tested.
3. Open LN2 dewar valve and allow to flow until PV-03-H is cooled and liquid is coming out of the vent. Then tighten dewar valve down to a slow trickle of gas coming out of the vent. This prevents air from getting inside the system.
4. Apply heat gun to Rad Lab connection until it is warm enough to properly connect the leak testing equipment to it (connection is made in step 6).
5. Open MV-00-He while the portable helium gas bottle is still unattached. Close PV-03-H.
6. Connect leak testing equipment at the Rad Lab connection.
7. Turn LN2 dewar valve completely off.
8. Using MV-00-He, apply helium gas pressure to the upstream area of the vent valve using the portable helium gas bottle.
9. Conduct leak test.

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## INTERLOCK SYSTEM TEST

Each interlock will be tested and documented for operability with a safety personnel on hand to witness its safe operation. The test results will be submitted to the Target Safety Committee.

## L. SAFETY CORRESPONDENCE

**To be determined**

## M. CALL-IN LIST

Chiranjib Dutta

Wolfgang Lorenzon

Kazutaka Nakahara

Richard Raymond

Wang Su-Yin