# Addendum: 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 17 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 by 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 precooling 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 precool 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. Fabric walls will be installed to reduce diffusion of vented hydrogen into gaps around FMag. 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 (LH₂, LD₂), 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 metallic 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.


- 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 connected to an APC 2200XL (2200VA-rated) uninterruptable power supply (UPS).

**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 Dynamics Research Corp C152-4211000120SS453 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

from flask vent

to flask fill

~6"

bolts(6)

to flask fill

~1.7"

~3.5"

1/2

from tgt fill

to tgt vent

Slots in fins to drain liquid

Figure 1
<table>
<thead>
<tr>
<th>Designation</th>
<th>Function</th>
<th>Manufacturer</th>
<th>Model</th>
<th>Range/Max working Press.</th>
<th>Size/Output</th>
<th>Notes</th>
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<tbody>
<tr>
<td>CV-101-D</td>
<td>PV-D2VV vent to tent Circle Seal</td>
<td>28OT-4PP-1</td>
<td>1 psig cracking pressure 1/2&quot;</td>
<td>Teflon Seals</td>
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<td>CV-01-H</td>
<td>PV-H2VV vent to tent Circle Seal</td>
<td>28OT-4PP-1</td>
<td>1 psig cracking pressure 1/2&quot;</td>
<td>Teflon Seals</td>
<td></td>
<td></td>
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<td>CV-01-N</td>
<td>N2 gas supply check valve Nupro CP</td>
<td>1 psid cracking pressure 1/4&quot;</td>
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<tr>
<td>CV-02-N</td>
<td>Air supply check valve Nupro CP</td>
<td>1 psid cracking pressure 1/4&quot;</td>
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<tr>
<th>Electric Valves</th>
<th>Function</th>
<th>Manufacturer</th>
<th>Model</th>
<th>Range/Max working Press.</th>
<th>Size/Output</th>
<th>Notes</th>
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<tbody>
<tr>
<td>EV-01-He</td>
<td>Fill/Empty valve solenoid, H2 system</td>
<td>Skinner V53DB2150, 110 VAC</td>
<td>150 psid 1/4&quot; 3-way, Normally Closed</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>EV-101-He</td>
<td>Fill/Empty valve solenoid, D2 system</td>
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<td>EV-D2VV</td>
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<td>EV-D2SUP</td>
<td>Supply valve solenoid</td>
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<td>150 psid 1/4&quot; 3-way, Normally Closed</td>
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<td>EV-D2FILL</td>
<td>Target fill valve solenoid</td>
<td>Skinner V53DB2150, 110 VAC</td>
<td>150 psid 1/4&quot; 3-way, Normally Closed</td>
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<td>EV-H2VV</td>
<td>Vent Valve solenoid</td>
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<td>150 psid 1/4&quot; 3-way, Normally Closed</td>
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<td>EV-H2SUP</td>
<td>H2 Supply valve solenoid</td>
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<td>150 psid 1/4&quot; 3-way, Normally Closed</td>
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<tr>
<td>EV-H2FILL</td>
<td>Target fill valve solenoid</td>
<td>Skinner V53DB2150, 110 VAC</td>
<td>150 psid 1/4&quot; 3-way, Normally Closed</td>
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<tr>
<td>EV-RPVVENTD</td>
<td>Rough pump vent valve</td>
<td>Skinner V53DB2150, 110 VAC</td>
<td>150 psid 1/4&quot; 3-way, Normally Closed</td>
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<td>EV-FPVVENTD</td>
<td>Forepump vent valve</td>
<td>Skinner V53DB2150, 110 VAC</td>
<td>150 psid 1/4&quot; 3-way, Normally Closed</td>
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<tr>
<td>EV-HPVVENTD</td>
<td>High Vacuum shutoff valve</td>
<td>Vacuumm Research LP4, 120VAC</td>
<td>Vacuum Valve 4&quot; 3-way, Normally Closed</td>
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<td>EV-WTRDRN</td>
<td>Air compressor water drain</td>
<td>Skinner V58DB2150, 110 VAC</td>
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<th>Excess Flow Valves</th>
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<th>Manufacturer</th>
<th>Model</th>
<th>Range/Max working Press.</th>
<th>Size/Output</th>
<th>Notes</th>
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<tr>
<td>EFV-101-D</td>
<td>D2 Excess flow valve</td>
<td>Nupro</td>
<td>6LE4LE-PR4-VR4 225 psig 1/4&quot; Burst Press. = 12000 psi</td>
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<td>EFV-01-H</td>
<td>H2 Excess flow valve</td>
<td>Nupro</td>
<td>6LE4LE-PR4-VR4 225 psig 1/4&quot; Burst Press. = 12000 psi</td>
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<tr>
<th>Electro-Pneumatic Valves</th>
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<th>Manufacturer</th>
<th>Model</th>
<th>Range/Max working Press.</th>
<th>Size/Output</th>
<th>Notes</th>
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<tr>
<td>EP-D2PURGE</td>
<td>Deuterium circuit purge valve</td>
<td>Skinner V5D4435, 120VAC</td>
<td>150 psid 1 1/8&quot; 3-way, Normally Closed</td>
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<td>EP-RF6VLVD</td>
<td>Rough pump shutoff valve</td>
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<td>150 psid 1 1/8&quot; 3-way, Normally Closed</td>
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<td>EP-FORVLVD</td>
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<td>EP-HVACD</td>
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<td>Vacuum Valve 4&quot; 3-way, Normally Closed</td>
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<td>EP-H2PURGE</td>
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<td>EP-RF6VLVH</td>
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<td>EP-FORVLVH</td>
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<td>EP-HIVACH</td>
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<th>Range/Max working Press.</th>
<th>Size/Output</th>
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<td>F-01-N</td>
<td>Air compressor filter</td>
<td>PALL</td>
<td>PA212100Av 1/4&quot; vendor supplied</td>
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C. VALVE AND INSTRUMENTATION LIST/FLOW DIAGRAM
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<tr>
<th>Manual Valves</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Model</th>
<th>Max. Pressure</th>
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<tr>
<td>MV-101-D</td>
<td>Post RV-101-D shutoff</td>
<td>NuPro</td>
<td>B-4HK2</td>
<td>1000 psig</td>
<td>1/4&quot;</td>
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<tr>
<td>MV-102-D</td>
<td>Pre pump cart shutoff valve</td>
<td>Matheson</td>
<td>103</td>
<td>3000 psig</td>
<td>1/4&quot;</td>
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<tr>
<td>MV-104-D</td>
<td>Cold trap inlet valve</td>
<td>NuPro</td>
<td>6L-LD8 2293</td>
<td>300 psig</td>
<td>1/2&quot;</td>
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<td>MV-105-D</td>
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<td>MV-106-D</td>
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<td>MV-111-D</td>
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<td>MV-112-D</td>
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<td>B-4HK2</td>
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<td>1/4&quot;</td>
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<tr>
<td>MV-113-D</td>
<td>PT-D2VENT pumpout valve</td>
<td>NuPro</td>
<td>B-4HK2</td>
<td>1000 psig</td>
<td>1/4&quot;</td>
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<tr>
<td>MV-01-H</td>
<td>Post RV-01-H shutoff</td>
<td>NuPro</td>
<td>B-4HK2</td>
<td>1000 psig</td>
<td>1/4&quot;</td>
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<tr>
<td>MV-02-H</td>
<td>Pre pump cart shutoff valve</td>
<td>Matheson</td>
<td>103</td>
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<td>MV-04-H</td>
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<td>MV-13-H</td>
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<td>MV-02-He</td>
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<td>Hoke</td>
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</tr>
<tr>
<td>MV-03-He</td>
<td>Helium Supply Valve</td>
<td>Hoke</td>
<td>4151M4B</td>
<td>601 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-01-N</td>
<td>Post nitrogen regulator shutoff</td>
<td>Linde</td>
<td>NA</td>
<td>3000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-02-N</td>
<td>Pre pump cart shutoff valve, H2 system</td>
<td>Hoke</td>
<td>4151M4B</td>
<td>600 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-03-N</td>
<td>PT-PN2SUP pumpout valve</td>
<td>NuPro</td>
<td>SS-4PAT4</td>
<td>3000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-04-N</td>
<td>PT-PN2SUP isolation valve</td>
<td>NuPro</td>
<td>SS-4PAT4</td>
<td>3000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-05-N</td>
<td>Filter/dryer isolation valve</td>
<td>NuPro</td>
<td>SS-4PAT4</td>
<td>3000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-06-N</td>
<td>Air compressor drain valve</td>
<td>NuPro</td>
<td>SS-4PAT4</td>
<td>3000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-07-N</td>
<td>Compressor water drain hand valve</td>
<td>Campbell-Hausfeld</td>
<td>vendor supplied</td>
<td>NA</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-08-N</td>
<td>Vent Valve pneumatic supply isolation</td>
<td>NuPro</td>
<td>SS-4PAT4</td>
<td>3000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-09-N</td>
<td>Air compressor isolation valve</td>
<td>NuPro</td>
<td>SS-4PAT4</td>
<td>3000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-10-N</td>
<td>Pump cart isolation valve</td>
<td>NuPro</td>
<td>SS-4PAT4</td>
<td>3000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-102-N</td>
<td>Pre pump cart shutoff valve, D2 system</td>
<td>Hoke</td>
<td>4151M4B</td>
<td>600 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-01-V</td>
<td>Rough line bleed valve, H2 system</td>
<td>Hoke</td>
<td>4151M4B</td>
<td>600 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-02-V</td>
<td>Fore pump vent valve, H2 system</td>
<td>Hoke</td>
<td>4151M4B</td>
<td>600 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-03-V</td>
<td>Vacuum shutoff to EV-01-He, H2 system</td>
<td>Hoke</td>
<td>4151M4B</td>
<td>600 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-101-V</td>
<td>Rough line bleed valve, D2 system</td>
<td>Hoke</td>
<td>4151M4B</td>
<td>600 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-102-V</td>
<td>Fore pump vent valve, D2 system</td>
<td>Hoke</td>
<td>4151M4B</td>
<td>600 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>MV-103-V</td>
<td>Vacuum shutoff to EV-01-He, D2 system</td>
<td>Hoke</td>
<td>4151M4B</td>
<td>600 psig</td>
<td>1/4&quot;</td>
</tr>
</tbody>
</table>
### Pneumatic Valves

<table>
<thead>
<tr>
<th>Valve Type</th>
<th>Description</th>
<th>Model</th>
<th>Pressure</th>
<th>Size</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV-D2SUP</td>
<td>D2 Supply Valve to Target</td>
<td>Nupro</td>
<td>SS-4BK-NC, Series 1</td>
<td>1000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>PV-D2FILL</td>
<td>D2 Target Fill Valve</td>
<td>Nupro</td>
<td>SS-4BK-NC, Series 1</td>
<td>1000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>PV-D2VVV</td>
<td>D2 Target Vent Valve</td>
<td>Nupro</td>
<td>SS8UWVCRTFT2-4C</td>
<td>2500 psig</td>
<td>1/2&quot;</td>
</tr>
<tr>
<td>PV-H2SUP</td>
<td>H2 Supply Valve to Target</td>
<td>Nupro</td>
<td>SS-4BK-NC, Series 1</td>
<td>1000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>PV-H2FILL</td>
<td>H2 Target Fill Valve</td>
<td>Nupro</td>
<td>SS-4BK-NC, Series 1</td>
<td>1000 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>PV-H2VVV</td>
<td>H2 Target Vent Valve</td>
<td>Nupro</td>
<td>SS8UWVCRTFT2-4C</td>
<td>2500 psig</td>
<td>1/2&quot;</td>
</tr>
</tbody>
</table>

### Regulators

<table>
<thead>
<tr>
<th>Regulator</th>
<th>Description</th>
<th>Model</th>
<th>Pressure</th>
<th>Size</th>
<th>NOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV-101-D</td>
<td>D2 Deuterium cylinder regulator</td>
<td>Victor</td>
<td>VTS-452B</td>
<td>2 to 40 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>RV-102-D</td>
<td>Pump cart D2 regulator</td>
<td>Air Products</td>
<td>E11-N141A</td>
<td>0 to 25 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>RV-01-H</td>
<td>Hydrogen cylinder regulator</td>
<td>Victor</td>
<td>VTS-452B</td>
<td>2 to 40 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>RV-01-N</td>
<td>Nitrogen cylinder regulator</td>
<td>Linde</td>
<td>UPG 3 150 580</td>
<td>0 to 150 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>RV-01-He</td>
<td>Helium cylinder regulator</td>
<td>Harris</td>
<td>93-350A</td>
<td>0 to 350 psig</td>
<td>1/4&quot;</td>
</tr>
<tr>
<td>RV-02-He</td>
<td>Helium supply regulator</td>
<td>Grove</td>
<td>202G</td>
<td>1&quot;</td>
<td></td>
</tr>
</tbody>
</table>

### Safety Valves

<table>
<thead>
<tr>
<th>Safety Valve</th>
<th>Description</th>
<th>Model</th>
<th>Pressure</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV-101-D</td>
<td>D2 Supply line relief</td>
<td>Nupro</td>
<td>B-8CPA2-3</td>
<td>110 psig</td>
</tr>
<tr>
<td>SV-10-H</td>
<td>D2 Cold trap relief valve</td>
<td>Nupro</td>
<td>B-8CPA2-3</td>
<td>10 psig</td>
</tr>
<tr>
<td>SV-03-H</td>
<td>Target H2 vent line relief</td>
<td>Anderson-Greenwood</td>
<td>83MB68-6</td>
<td>10 psig</td>
</tr>
<tr>
<td>SV-04-H</td>
<td>H2 Cold trap relief valve</td>
<td>Nupro</td>
<td>B-8CPA2-3</td>
<td>50 psig</td>
</tr>
<tr>
<td>SV-01-N</td>
<td>Nitrogen gas supply relief</td>
<td>Circle Seal</td>
<td>5159B-4MP</td>
<td>140 psig</td>
</tr>
<tr>
<td>SV-02-N</td>
<td>Air compressor relief</td>
<td>Campbell-Hausfield</td>
<td>SP25</td>
<td>140 psig</td>
</tr>
<tr>
<td>SV-01-V</td>
<td>Refrigerator can, H2 system</td>
<td>Fermilab design</td>
<td>parallel plate</td>
<td>lift pressure &lt;= 3.5 psid</td>
</tr>
<tr>
<td>SV-02-V</td>
<td>Refrigerator can, H2 system</td>
<td>Fermilab design</td>
<td>parallel plate</td>
<td>lift pressure &lt;= 3.5 psid</td>
</tr>
<tr>
<td>SV-10-V</td>
<td>Target vacuum relief, D2 system</td>
<td>Fermilab design</td>
<td>parallel plate</td>
<td>lift pressure &lt;= 3.5 psid</td>
</tr>
<tr>
<td>SV-01-He</td>
<td>Helium gas supply relief, H2 system</td>
<td>Nupro</td>
<td>B-8CPA2-3</td>
<td>300 psig</td>
</tr>
</tbody>
</table>

### Analyzers

<table>
<thead>
<tr>
<th>Analyzer</th>
<th>Description</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE-01</td>
<td>Flammable gas detector</td>
<td>Controls Instruments</td>
</tr>
<tr>
<td>AIS-01</td>
<td>Detector indication switch</td>
<td>Controls Instruments</td>
</tr>
</tbody>
</table>

### Flow Devices

<table>
<thead>
<tr>
<th>Flow Device</th>
<th>Description</th>
<th>Model</th>
<th>Pressure</th>
<th>Flow Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT-D2SUP</td>
<td>Deuterium gas supply flow</td>
<td>MKS</td>
<td>0558C-050L-GV-SPCAL-H2</td>
<td>0 to 50 slpm H2</td>
</tr>
<tr>
<td>FT-H2SUP</td>
<td>Hydrogen gas supply flow</td>
<td>MKS</td>
<td>0558C-050L-GV-SPCAL-H2</td>
<td>0 to 50 slpm H2</td>
</tr>
<tr>
<td>FT-TENTFAN</td>
<td>Tent fan flow</td>
<td>Annubar</td>
<td>AIR-26 for 10&quot; circ. duct</td>
<td></td>
</tr>
<tr>
<td>FS-TENTFAN</td>
<td>Tent fan flow indication</td>
<td>Annubar</td>
<td>EF-W</td>
<td>0 to 1500 actual CFM air</td>
</tr>
</tbody>
</table>
### 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-RPVCAD | Rough pump vacuum | Fredericks Televac | 2A | 0 to 1000 micron | 0 to 7 volts |
| PE-PPVCAV | 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-PPVACH | 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 | FIXEMACS |
| 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 | FIXEMACS |
| 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 | FIXEMACS |
| PI-02-He | 1" He discharge header pressure, H2 tgt | FIXEMACS |
| 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 pump cart | US Gauge | 0 to 100 psig |
| PI-06-N | Air compressor supply pressure | US Gauge | 0 to 200 psig |
| PI-01-V | PT-01-V readout device, H2 tgt | MKS Instruments | PDR-C-2C-BCD | 0 to 10 mbar |
| PI-02-V | PT-02-V readout device, H2 tgt | MKS Instruments | PDR-C-2C-BCD | 0 to 1000 mbar |
| 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 mbar |
| PI-102-V | PT-02-V readout device, D2 tgt | MKS Instruments | PDR-C-2C-BCD | 0 to 1000 mbar |
| PI-103-V | Insulating vacuum, D2 tgt | Fredericks Televac | 7B | 10-3 to 10-8 Torr |
### PRESSURE TRANSMITTERS

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Description</th>
<th>Brand</th>
<th>Range</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT-D2SUP</td>
<td>Deuterium supply pressure</td>
<td>Setra</td>
<td>0 to 50 psia</td>
<td>0 to 5 Volts</td>
</tr>
<tr>
<td>PT-D2VENT</td>
<td>Deuterium flask pressure</td>
<td>Setra</td>
<td>0 to 50 psia</td>
<td>0 to 5 Volts</td>
</tr>
<tr>
<td>PT-H2SUP</td>
<td>Hydrogen supply pressure</td>
<td>Setra</td>
<td>0 to 50 psia</td>
<td>0 to 5 Volts</td>
</tr>
<tr>
<td>PT-H2VENT</td>
<td>Hydrogen flask pressure</td>
<td>Setra</td>
<td>0 to 50 psia</td>
<td>0 to 5 Volts</td>
</tr>
<tr>
<td>PT-COMPOISH</td>
<td>1&quot; He discharge header pressure, H2 tgt</td>
<td>Ashcroft</td>
<td>0 to 500 psig</td>
<td>4 to 20 mA</td>
</tr>
<tr>
<td>PT-COMPOISD</td>
<td>1&quot; He discharge header pressure, D2 tgt</td>
<td>Ashcroft</td>
<td>0 to 500 psig</td>
<td>4 to 20 mA</td>
</tr>
<tr>
<td>PT-PN2SUP</td>
<td>Pneumatic supply pressure</td>
<td>Setra</td>
<td>0 to 500 psig</td>
<td>4 to 20 mA</td>
</tr>
<tr>
<td>PT-01-V</td>
<td>Insulating Vacuum Pressure, H2 tgt</td>
<td>MKS Instruments</td>
<td>0 to 10 mmHg</td>
<td>0 to 10 volts</td>
</tr>
<tr>
<td>PT-02-V</td>
<td>Insulating Vacuum Pressure, H2 tgt</td>
<td>MKS Instruments</td>
<td>0 to 1000 mmHg</td>
<td>0 to 10 volts</td>
</tr>
<tr>
<td>PT-101-V</td>
<td>Insulating Vacuum Pressure, D2 tgt</td>
<td>MKS Instruments</td>
<td>0 to 10 mmHg</td>
<td>0 to 10 volts</td>
</tr>
<tr>
<td>PT-102-V</td>
<td>Insulating Vacuum Pressure, D2 tgt</td>
<td>MKS Instruments</td>
<td>0 to 1000 mmHg</td>
<td>0 to 10 volts</td>
</tr>
</tbody>
</table>

### SWITCHES

<table>
<thead>
<tr>
<th>Switch</th>
<th>Description</th>
<th>Brand</th>
<th>Range</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISL-FPD</td>
<td>Current switch low</td>
<td>SSAC</td>
<td>adjustable 2 to 20 Amps</td>
<td>12 VDC on D2 system Fore Pump</td>
</tr>
<tr>
<td>ISL-RPD</td>
<td>Current switch low</td>
<td>SSAC</td>
<td>adjustable 2 to 20 Amps</td>
<td>12 VDC on D2 system Rough Pump</td>
</tr>
<tr>
<td>ISL-FPH</td>
<td>Current switch low</td>
<td>SSAC</td>
<td>adjustable 2 to 20 Amps</td>
<td>12 VDC on H2 system Fore Pump</td>
</tr>
<tr>
<td>ISL-RPH</td>
<td>Current switch low</td>
<td>SSAC</td>
<td>adjustable 2 to 20 Amps</td>
<td>12 VDC on H2 system Rough Pump</td>
</tr>
<tr>
<td>PS-01-N</td>
<td>Air compressor ON-OFF</td>
<td>Condor</td>
<td>160 psig</td>
<td>110/135 psig set pts.</td>
</tr>
</tbody>
</table>

### TEMPERATURE ELEMENTS

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
<th>Brand</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE-D2FLUP</td>
<td>Deuterium flask top</td>
<td>Allen-Bradley</td>
<td>100 Ohm</td>
</tr>
<tr>
<td>TE-D2FLDN</td>
<td>Deuterium flask down</td>
<td>Allen-Bradley</td>
<td>100 Ohm</td>
</tr>
<tr>
<td>TE-D2CPOT</td>
<td>D2 condenser</td>
<td>Lakeshore</td>
<td>CX-1030-SD cernox</td>
</tr>
<tr>
<td>TE-D2SVEHX</td>
<td>D2 AGCO safety valve exhaust</td>
<td>Lakeshore</td>
<td>PT 102 Platinum RTD</td>
</tr>
<tr>
<td>TE-H2FLUP</td>
<td>Hydrogen flask top</td>
<td>Allen-Bradley</td>
<td>100 Ohm</td>
</tr>
<tr>
<td>TE-H2FLDN</td>
<td>Hydrogen flask down</td>
<td>Allen-Bradley</td>
<td>100 Ohm</td>
</tr>
<tr>
<td>TE-H2CPOT</td>
<td>H2 condenser</td>
<td>Lakeshore</td>
<td>CX-1030-SD cernox</td>
</tr>
<tr>
<td>TE-H2SVEHX</td>
<td>H2 AGCO safety valve exhaust</td>
<td>Lakeshore</td>
<td>PT 102 Platinum RTD</td>
</tr>
</tbody>
</table>

### TEMPERATURE SWITCHES

<table>
<thead>
<tr>
<th>Switch</th>
<th>Description</th>
<th>Brand</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSH-01-W</td>
<td>Temperature switch H compressor</td>
<td>Cryomech</td>
</tr>
<tr>
<td>TSD-01-W</td>
<td>Temperature switch D compressor</td>
<td>Cryomech</td>
</tr>
</tbody>
</table>
From Refrigerator LH2 (sheet 1)

CRYOMECH HCOM AL230

TSH–01–W is inside the compressor

From Refrigerator LD2 (sheet 2)

CRYOMECH DCOM AL230

TSD–01–W is inside the compressor

Two compressors used for the targets

To PV–H2VV (Sheet 1)
To PV–D2VV (Sheet 2)
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 > 1000 torr or PT-H2SUP>1000torr
   
   Hydrogen vent valve, PV-H2VV, is opened. Beam is turned off. Heater is turned off.

4. Deuterium flask pressure PT-D2VENT > 1000 torr or PT-D2SUP>1000torr
   
   Deuterium vent valve, PV-D2VV, is opened. Beam is turned off. Heater is turned off.

5. TSH-01-W high
   
   Factory set temperature switch. Shuts down compressor if the gas outlet temperature is too high.

6. TSD-01-W high
   
   Factory set temperature switch. Shuts down compressor if the gas outlet temperature is too high.

7. 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.
   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. A complete failure would result in reduction of He line pressure PT-HCOMP. 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 HI and HIHI will trigger an alarm.

19. Current switch ISLFPD HI and HIHI will trigger an alarm.

20. Current switch ISLRPH HI and HIHI will trigger an alarm.

21. Current switch ISLRPD HI and HIHI 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.

<table>
<thead>
<tr>
<th>By</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>_____</td>
<td>Target placed into position in beam line.</td>
</tr>
<tr>
<td>2.</td>
<td>_____</td>
<td>H2 Pump Cart in position.</td>
</tr>
<tr>
<td>3.</td>
<td>_____</td>
<td>Ground connection to target.</td>
</tr>
<tr>
<td>4.</td>
<td>_____</td>
<td>Foreline connected to target.</td>
</tr>
<tr>
<td>5.</td>
<td>_____</td>
<td>H2 supply line connected to target.</td>
</tr>
<tr>
<td>6.</td>
<td>_____</td>
<td>Roughing line connected to target.</td>
</tr>
<tr>
<td>7.</td>
<td>_____</td>
<td>Refrigerator gas lines connected and leak checked.</td>
</tr>
<tr>
<td>8.</td>
<td>_____</td>
<td>Hydrogen &amp; pneumatic lines connected to pump cart.</td>
</tr>
<tr>
<td>9.</td>
<td>_____</td>
<td>Pressure transducer cables connected to both transducers, PT-H2SUP and PT-H2VENT.</td>
</tr>
<tr>
<td>10.</td>
<td>_____</td>
<td>Discharge gauge connected (gauge powered only when hydrogen is not present)</td>
</tr>
<tr>
<td>11.</td>
<td>_____</td>
<td>Connect target table controller cables to target table.</td>
</tr>
<tr>
<td>12.</td>
<td>_____</td>
<td>Cryostat instrumentation cables connected to cryostat.</td>
</tr>
<tr>
<td>13.</td>
<td>_____</td>
<td>Pump cart control cable connected.</td>
</tr>
<tr>
<td>14.</td>
<td>_____</td>
<td>Diffusion pump and high vacuum valve cable connected.</td>
</tr>
<tr>
<td>15.</td>
<td>_____</td>
<td>220 Volts 3 phase 60 amp disconnect checked for 15 amp fuses. Replace fuses if they are larger.</td>
</tr>
<tr>
<td>16.</td>
<td>_____</td>
<td>Plug pump cart into 220 volt receptacle.</td>
</tr>
<tr>
<td>17.</td>
<td>_____</td>
<td>Plug hydrogen compressor power cable to 220 volt receptacle.</td>
</tr>
<tr>
<td>18.</td>
<td>_____</td>
<td>Connect pump cart cable to breakout box.</td>
</tr>
<tr>
<td>19.</td>
<td>_____</td>
<td>Connect PT-01-V gauge cable to breakout box.</td>
</tr>
<tr>
<td>20.</td>
<td>_____</td>
<td>Connect refrigerator cable to compressor package.</td>
</tr>
</tbody>
</table>
21. _____  _____  Connect water hoses to hydrogen compressor package.
22. _____  _____  Cryostat instrumentation cables connected to breakout box.
23. _____  _____  Connect Flammable Gas detector cable to control rack.
24. _____  _____  Tie down all cables and lines, check for interference with target table motion, correct where necessary.
25. _____  _____  Do general housekeeping around target area.
26. _____  _____  Install guards over cables and lines when necessary.
27. _____  _____  Remove guard on target windows when appropriate.
28. _____  _____  Install rotating warning lights in vicinity of target and in pump cart area.
29. _____  _____  Install warning signs at designated locations.
30. _____  _____  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.


- Regulators backed off
### Control Console

<table>
<thead>
<tr>
<th>By</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>______</td>
<td>______</td>
<td>All cables connected to rack.</td>
</tr>
<tr>
<td>______</td>
<td>______</td>
<td>Power on to programmable logic controller.</td>
</tr>
<tr>
<td>______</td>
<td>______</td>
<td>Power on to target control system computer.</td>
</tr>
<tr>
<td>______</td>
<td>______</td>
<td>Power to Flammable Gas Detector. Test alarm whooper and reset.</td>
</tr>
<tr>
<td>______</td>
<td>______</td>
<td>Check housekeeping in area around control console.</td>
</tr>
<tr>
<td>______</td>
<td>______</td>
<td>Check that UPS is operational.</td>
</tr>
</tbody>
</table>

### Cylinders and System Regulators Installation  
Note: Keep cylinder valves closed at this time.

<table>
<thead>
<tr>
<th>By</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>______</td>
<td>______</td>
<td>Nitrogen cylinder installed with RV-01-N for pneumatic air backup.</td>
</tr>
<tr>
<td>______</td>
<td>______</td>
<td>Air compressor installed with RV-02-N for pneumatic air supply.</td>
</tr>
<tr>
<td>______</td>
<td>______</td>
<td>Check compressor helium pressure (200-210 psi).</td>
</tr>
<tr>
<td>______</td>
<td>______</td>
<td>Hydrogen cylinder installed with RV-01-H for liquid hydrogen target purge and fill.</td>
</tr>
</tbody>
</table>
LH2 TARGET STARTING/RESTARTING CHECK LIST

Target Area

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

Note: Steps 12 and 13 should be performed in step 17 of Target Starting Procedure during initial startup of system.

12.    ______  ______       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.

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

14.    ______  ______       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.

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

16.    ______  ______       Install covers over cylinders where necessary.

17.    ______  ______       Hydrogen 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. _______ Close hand valve, MV-01-V, at roughing pump port vent and cap; Close Hand valve, MV-02-V, at forepump port vent and cap.

3. _______ Check oil level in vacuum pumps.

4. _______ 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.

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

6. _______ Turn on forepump. Pressure should reach 20 microns on PE-FPVACH in 2 minutes.

7. _______ Open fore line valve EP-FORVLVH.

8. _______ Open roughing valve EP-RUFVLVH to target insulating vacuum.

9. _______ Turn on power to diffusion pump.

10. _______ 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.

11. _______ Be sure that MV-04-H, MV-06-H, MV-10-H and MV-12-H are open.


13. _______ Check that the PLC interlock is enabled for the vent valve, PV-H2VV.

14. _______ 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.

15. _______ Notify operations center(?) that SeaQuest target is being purged to Hydrogen.

16. _______ Secure the target tent and the area around the target. Close access gates if provided. Start controlled access into area.
17. ____  Be sure MV-01-H and MV-02-H are open.

18. ____  Perform steps 12 and 13 of the Target Starting/Restarting Check List now.

19. ____  Verify that EFV-01-H is positioned correctly.

20. ____  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.

21. ____  Target pressure read on pressure transducer PT-H2VENT should reach approximately 17.5 psia.


23. ____  Cool down the Hydrogen cold trap.

24. ____  Turn on hydrogen compressor.

25. ____  Turn on heater and heater control circuit to reach 14.5 psig.

26. ____  Monitor condenser temperature.

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

28. ____  Continue to fill the target with 1.89 liters after TE-H2FLUP sees liquid.


30. ____  Gradually adjust the flask pressure to 14.7 psig.

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

32. ____  Pump out the cold trap by opening EP-H2Purge and PV-H2Fill. Evacuate cold trap until warm.
33. ________ 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. _______ 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.

4. _______ 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:

5. _______ 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. _______ Confirm that the hydrogen cylinder supply valve is closed.

NOTE: BACKFILLING OF CIRCUIT MUST 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. _______  Turn on heater controller and be sure the set pressure is 14.5 psia.

5. _______  Check the hydrogen circuit upper and lower resistors as some hydrogen may need to be added to the hydrogen circuit.

6. _______  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. Check SV-02-H has been lifted and resealed.

7. _______  Close PV-H2FILL and PV-H2SUP.
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.

<table>
<thead>
<tr>
<th>By</th>
<th>Date</th>
<th>Task Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td>Target placed into position in beam line.</td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td>D2 Pump Cart in position.</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td>Ground connection to target.</td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td>Foreline connected to target.</td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td>D2 supply line connected to target.</td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td>Roughing line connected to target.</td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td>Refrigerator gas lines connected and leak checked.</td>
</tr>
<tr>
<td>8.</td>
<td></td>
<td>Deuterium, &amp; pneumatic lines connected to pump cart.</td>
</tr>
<tr>
<td>9.</td>
<td></td>
<td>Pressure transducer cable connected to both transducers, PT-D2SUP and PT-D2VENT.</td>
</tr>
<tr>
<td>10.</td>
<td></td>
<td>Discharge gauge connected (gauge powered only when hydrogen is not present)</td>
</tr>
<tr>
<td>11.</td>
<td></td>
<td>Connect target table controller cables to target table.</td>
</tr>
<tr>
<td>12.</td>
<td></td>
<td>Cryostat instrumentation cables connected to cryostat.</td>
</tr>
<tr>
<td>13.</td>
<td></td>
<td>Pump cart control cable connected.</td>
</tr>
<tr>
<td>14.</td>
<td></td>
<td>Diffusion pump and high vacuum valve cable connected.</td>
</tr>
<tr>
<td>15.</td>
<td></td>
<td>220 Volts 3 phase 60 amp disconnect checked for 15 amp fuses. Replace fuses if they are larger.</td>
</tr>
<tr>
<td>16.</td>
<td></td>
<td>Plug pump cart into 220 volt receptacle.</td>
</tr>
<tr>
<td>17.</td>
<td></td>
<td>Plug deuterium compressor power cable to 220 volt receptacle.</td>
</tr>
<tr>
<td>18.</td>
<td></td>
<td>Connect pump cart cable to breakout box.</td>
</tr>
<tr>
<td>19.</td>
<td></td>
<td>Connect PT-101-V gauge cable to breakout box.</td>
</tr>
<tr>
<td>20.</td>
<td></td>
<td>Connect refrigerator cable to compressor package.</td>
</tr>
<tr>
<td>21.</td>
<td></td>
<td>Connect water hoses to hydrogen compressor package.</td>
</tr>
<tr>
<td>22.</td>
<td></td>
<td>Cryostat instrumentation cables connected to breakout box.</td>
</tr>
<tr>
<td>23.</td>
<td></td>
<td>Connect Flammable Gas detector cable to control rack.</td>
</tr>
<tr>
<td>24.</td>
<td></td>
<td>Tie down all cables and lines, check for interference with manipulators, correct where necessary.</td>
</tr>
</tbody>
</table>
25. _____  _____  Do general housekeeping around target area.
26. _____  _____  Install guards over cables and lines when necessary.
27. _____  _____  Remove guard on target windows when appropriate.
28. _____  _____  Install rotating warning lights in vicinity of target and in pump cart area.
29. _____  _____  Install warning signs at designated locations.
30. _____  _____  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.


- Regulators backed off
Control Console

<table>
<thead>
<tr>
<th>By</th>
<th>Date</th>
<th>Task Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>______  ______</td>
<td>All cables connected to rack.</td>
</tr>
<tr>
<td>2.</td>
<td>______  ______</td>
<td>Power on to programmable logic controller.</td>
</tr>
<tr>
<td>3.</td>
<td>______  ______</td>
<td>Power on to target control system computer.</td>
</tr>
<tr>
<td>4.</td>
<td>______  ______</td>
<td>Power to Flammable Gas Detector. Test alarm whooper and reset.</td>
</tr>
<tr>
<td>5.</td>
<td>______  ______</td>
<td>Check housekeeping in area around control console.</td>
</tr>
</tbody>
</table>

Cylinders and System Regulators Installation  Note: Keep cylinder valves closed at this time.

<table>
<thead>
<tr>
<th>By</th>
<th>Date</th>
<th>Task Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>______  ______</td>
<td>Nitrogen cylinder installed with RV-01-N for pneumatic air backup.</td>
</tr>
<tr>
<td>2.</td>
<td>______  ______</td>
<td>Air compressor installed with RV-02-N for pneumatic air supply.</td>
</tr>
<tr>
<td>3.</td>
<td>______  ______</td>
<td>Check compressor helium pressure (200-210 psi).</td>
</tr>
<tr>
<td>4.</td>
<td>______  ______</td>
<td>Deuterium cylinder installed with RV-01-H for liquid deuterium target purge and fill.</td>
</tr>
</tbody>
</table>
**LD2 TARGET STARTING/RESTARTING CHECK LIST**

**Target Area**

<table>
<thead>
<tr>
<th>By</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>______</td>
<td>No physical damage to equipment.</td>
</tr>
<tr>
<td>2.</td>
<td>______</td>
<td>No physical damage to lines.</td>
</tr>
<tr>
<td>3.</td>
<td>______</td>
<td>No physical damage to cables.</td>
</tr>
<tr>
<td>4.</td>
<td>______</td>
<td>Alignment check.</td>
</tr>
<tr>
<td>5.</td>
<td>______</td>
<td>Target windows intact.</td>
</tr>
<tr>
<td>6.</td>
<td>______</td>
<td>Vacuum pump oil level normal.</td>
</tr>
<tr>
<td>7.</td>
<td>______</td>
<td>All lines connected to target and pump cart.</td>
</tr>
<tr>
<td>8.</td>
<td>______</td>
<td>Rotating lights turned on.</td>
</tr>
<tr>
<td>9.</td>
<td>______</td>
<td>Both disconnects and all circuit breakers on.</td>
</tr>
<tr>
<td>10.</td>
<td>______</td>
<td>Nitrogen pressure is OK.</td>
</tr>
<tr>
<td>11.</td>
<td>______</td>
<td>Air compressor is operational.</td>
</tr>
</tbody>
</table>

Note: Steps 12 and 13 should be performed in step 17 of Target Starting Procedure during initial startup of system.

12. ______       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.

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

14. ______       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.

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

16. ______       Open MV-13-He and set RV-04-He to 3 psig. Note pressure ______

17. ______       Install covers over cylinders where necessary.

18. ______       Flammable Gas Detector in place.
19. ______   ______  Housekeeping in area around target is good.

20. ______   ______  All warning signs in area prominently displayed and unobstructed.
TARGET STARTING PROCEDURE

1. _______ Close hand valve, MV-101-V, at roughing pump port vent and cap; Close Hand valve, MV-102-V, at for pump port vent and cap.

2. _______ Close MV-103-V, EV-101-He and MV-102-He. MV-102-He is to be capped.

3. _______ Check oil levels in vacuum pumps.


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

6. _______ Turn on forepump. Pressure should reach 20 microns on PE-FPVACD in 2 minutes.

7. _______ Open fore line valves EP-FORVLVD.

8. _______ Open roughing valve EP-RUFVLVD to target insulating vacuum.

9. _______ Turn on power to diffusion pump.

10. _______ 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-RUFVLVD closes automatically. This occurs at 75 microns.

11. _______ Be sure that MV-104-D, MV-106-D, MV-110-D and MV-112-D are open.

12. _______ Be sure that MV-105-D, MV-107-D, MV-111-D and MV-113-D are closed.

13. _______ Check that the PLC interlock is enabled for the vent valve, PV-D2VV.

14. _______ 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.

15. _______ Notify operations center that SEAQUEST target is being purged to deuterium.
16.________ Secure the target tent and the area around the target. Close access gates if provided. Start controlled access into area.

17. _______ Be sure MV-101-D and MV-102-D are open.

18. _______ Perform steps 12 and 13 of the Target Starting/Restarting Check List now.

19. _______ Verify that EFV-101-D is positioned correctly.

20. _______ After the deuterium supply line and cold trap are pumped out to 30 microns, close purge valve, EP-D2PURGE. Open hydrogen supply 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.

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

22. _______ 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 open and EP-D2PURGE closed.

23. _______ Cool down the Deuterium cold trap.

24. _______ Turn on deuterium compressor.

25. _______ Start the deuterium system compressor flow and refrigerator.

26. _______ Monitor refrigerator temperature.

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

28. _______ Continue to fill the target with 1.89 liters after TE-D2FLUP sees liquid.

29. _______ Close the deuterium supply valve, PV-D2SUP, and the deuterium fill valve, PV-D2FILL. Close the deuterium cylinder supply valve and manual valves.

30. _______ Turn on heater and heater control circuit to reach 14.5 psig.

31. _______ Gradually adjust the flask pressure to 14.7 psig.

32. _______ Close MV-106-D (MV-105-D is already closed). Remove the cold trap from the liquid nitrogen.
33. _______  Pump out the cold trap by opening EP-D2Purge and PV-D2Fill. Evacuate cold trap until warm.

34. _______  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. ______  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.
4. ______  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:

5. ______  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.
6. ______  Close PV-D2SUP. Open PV-D2FILL and EP-D2PURGE. Pump out the target deuterium circuit. The deuterium gas is vented through the roughing pump.
7. ______  Confirm that the deuterium cylinder supply valve is closed.

NOTE: BACKFILLING OF CIRCUIT MUST OCCUR IN THIS ORDER TO AVOID CRUSHING THE TARGET 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. _______  Turn on the heater controller and be sure the set pressure is 14.5 psia.

5. _______  Check the deuterium circuit upper and lower resistors as some deuterium may need to be added to the deuterium circuit.

6. _______  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. Check SV-102-D has been lifted and resealed.

7. _______  Close PV-D2FILL and PV-D2SUP.
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 System.

   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, the hydrogen and deuterium will vaporize. Hydrogen and deuterium will be vented outside of the target tent. 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 keep the control system alive, which will 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 surrounded by a tent. The tent is vented into the hall through a large fan. The fan is continuously running.

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.
- Valves don’t respond.
- Insulating vacuum spoils.

a. Loss of air/nitrogen will cause all vacuum valves except the high vacuum valve to close. The high vacuum valve will remain in its previous position.
c. Check for leaks.
d. Perform required maintenance to air compressor system.
e. Check target operation indicators. Hydrogen/Deuterium may need to be added.
   Refill as necessary.
f. 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.
- 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 would not cause a loss of refrigeration on the other. A loss of refrigeration on one target may cause that target to warm up and vent through the vent

5. LOSS OF THE VENT FAN FROM THE TARGET ENCLOSURE

Indications:

- Alarm on FIS-TENTFAN
- Power Outage
- Failure of the flow sensing device

a. Beam is turned off.
b. If the vent fan or sensor for the SeaQuest hall has failed, the fan should be replaced.
   Spares are available.
c. Target table motor is turned off.
## Check Valves

<table>
<thead>
<tr>
<th>Designation</th>
<th>Failure or Error Code</th>
<th>Hazard/Effect</th>
<th>Hazard Class</th>
<th>Remarks/Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV-101-D</td>
<td>Open</td>
<td>Target D2 vents when PV-D2VV is open</td>
<td>Safe</td>
<td>PV-D2VV prevents backflow of air if CV-101-D is stuck open</td>
</tr>
<tr>
<td>CV-101-D</td>
<td>Closed</td>
<td>Target pressure may increase to SV-103-D set point (10 psig)</td>
<td>Safe</td>
<td>PSV-103-D would relieve any excess pressure</td>
</tr>
<tr>
<td>CV-01-H</td>
<td>Open</td>
<td>Target H2 vents when PV-H2VV is open</td>
<td>Safe</td>
<td>PV-H2VV prevents backflow of air if CV-01-H is stuck open</td>
</tr>
<tr>
<td>CV-01-N</td>
<td>Closed</td>
<td>Pneumatic air from compressor may leak through RV-01-N vent</td>
<td>Safe</td>
<td>Supply pressure to pneumatic valves will not go below RV-01-N setting</td>
</tr>
<tr>
<td>CV-01-N</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
<td>Maintains a pressure of 60 psig (RV-02-N setting) to pneumatic valves</td>
</tr>
<tr>
<td>CV-02-N</td>
<td>Open</td>
<td>Normal operating position</td>
<td>Safe</td>
<td>Keeps pneumatic valves operative</td>
</tr>
<tr>
<td>CV-02-N</td>
<td>Closed</td>
<td>Pneumatic air from compressor will not be available</td>
<td>Safe</td>
<td>N2 pneumatic supply will continue to pressurize pneumatic lines</td>
</tr>
</tbody>
</table>

## Electric Valves

<table>
<thead>
<tr>
<th>Designation</th>
<th>Failure or Error Code</th>
<th>Hazard/Effect</th>
<th>Hazard Class</th>
<th>Remarks/Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>EV-D2VV</td>
<td>Open</td>
<td>PV-D2VV Target is vented</td>
<td>Safe</td>
<td>Operates when target pressure exceeds 7 psig</td>
</tr>
<tr>
<td>EV-D2VV</td>
<td>Closed</td>
<td>PV-D2VV would close, target pressure may increase to SV-103-D set point</td>
<td>Safe</td>
<td>SV-103-D relieves target when pressure exceeds 10 psig</td>
</tr>
<tr>
<td>EV-D2SUP</td>
<td>Open</td>
<td>PV-D2SUP would open, supplying target with D2 during fill</td>
<td>Safe</td>
<td>Normal during fill; duration operation, all D2 supply is off</td>
</tr>
<tr>
<td>EV-D2SUP</td>
<td>Closed</td>
<td>Normal during operation</td>
<td>Safe</td>
<td>Target cannot fill</td>
</tr>
<tr>
<td>EV-D2FILL</td>
<td>Open</td>
<td>PV-D2FILL would open, supplying target with D2 during fill</td>
<td>Safe</td>
<td>Normal during fill; duration operation, all D2 supply is off</td>
</tr>
<tr>
<td>EV-D2FILL</td>
<td>Closed</td>
<td>Normal during operation</td>
<td>Safe</td>
<td>Target cannot fill</td>
</tr>
<tr>
<td>EV-RPVENTD</td>
<td>Open</td>
<td>Rough pump is vented to air</td>
<td>Safe</td>
<td>EP-RUFVLVD must be closed to prevent loss of vacuum</td>
</tr>
<tr>
<td>EV-RPVENTD</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
<td>Rough pump operation proceeds normally</td>
</tr>
<tr>
<td>EV-FPVENTD</td>
<td>Open</td>
<td>Fore pump is vented to air</td>
<td>Safe</td>
<td>EP-FORVLVD must be closed to prevent loss of vacuum</td>
</tr>
<tr>
<td>EV-FPVENTD</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
<td>Fore Vacuum system operation proceeds normally</td>
</tr>
<tr>
<td>EV-H2VV</td>
<td>Open</td>
<td>PV-H2VV Target is vented</td>
<td>Safe</td>
<td>Operates when target pressure exceeds 7 psig</td>
</tr>
<tr>
<td>EV-H2VV</td>
<td>Closed</td>
<td>PV-H2VV would close, target pressure may increase to SV-103-H set point</td>
<td>Safe</td>
<td>SV-103-H relieves target when pressure exceeds 10 psig</td>
</tr>
<tr>
<td>EV-H2SUP</td>
<td>Open</td>
<td>PV-H2SUP would open, supplying target with H2 during fill</td>
<td>Safe</td>
<td>Normal during fill; duration operation, all H2 supply is off</td>
</tr>
<tr>
<td>EV-H2SUP</td>
<td>Closed</td>
<td>Normal during operation</td>
<td>Safe</td>
<td>Target cannot fill</td>
</tr>
<tr>
<td>EV-H2FILL</td>
<td>Open</td>
<td>PV-H2FILL would open, supplying target with H2 during fill</td>
<td>Safe</td>
<td>Normal during fill; duration operation, all H2 supply is off</td>
</tr>
<tr>
<td>EV-H2FILL</td>
<td>Closed</td>
<td>Normal during operation</td>
<td>Safe</td>
<td>Target cannot fill</td>
</tr>
<tr>
<td>EV-RPVENTH</td>
<td>Open</td>
<td>Rough pump is vented to air</td>
<td>Safe</td>
<td>EP-RUFVLVH must be closed to prevent loss of vacuum</td>
</tr>
<tr>
<td>EV-RPVENTH</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
<td>Rough pump operation proceeds normally</td>
</tr>
<tr>
<td>EV-FPVENTH</td>
<td>Open</td>
<td>Fore pump is vented to air</td>
<td>Safe</td>
<td>EP-FORVLVH must be closed to prevent loss of vacuum</td>
</tr>
<tr>
<td>EV-FPVENTH</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
<td>Fore Vacuum system operation proceeds normally</td>
</tr>
<tr>
<td>EV-01-He</td>
<td>Open</td>
<td>Redundant equipment MV-02-He and MV-03-V are closed</td>
<td>Safe</td>
<td>Normally not used</td>
</tr>
<tr>
<td>EV-01-He</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
<td>Normally not used</td>
</tr>
<tr>
<td>EV-101-He</td>
<td>Open</td>
<td>Redundant equipment, MV-02-He and MV-03-V are closed</td>
<td>Safe</td>
<td>Normally not used</td>
</tr>
<tr>
<td>EV-101-He</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
<td>Normally not used</td>
</tr>
<tr>
<td>EV-WTRDRN</td>
<td>Open</td>
<td>Safe</td>
<td>Safe</td>
<td></td>
</tr>
<tr>
<td>EV-WTRDRN</td>
<td>Closed</td>
<td>Safe</td>
<td>Safe</td>
<td></td>
</tr>
</tbody>
</table>

## Excess Flow Valves

<table>
<thead>
<tr>
<th>Designation</th>
<th>Failure or Error Code</th>
<th>Hazard/Effect</th>
<th>Hazard Class</th>
<th>Remarks/Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFV-101-D</td>
<td>Open</td>
<td>Normal during fill</td>
<td>Safe</td>
<td></td>
</tr>
<tr>
<td>EFV-101-D</td>
<td>Closed</td>
<td>Target will not fill; High flow may have caused valve to close</td>
<td>Safe</td>
<td>D2 line may have leak</td>
</tr>
<tr>
<td>EFV-101-H</td>
<td>Open</td>
<td>Normal during fill</td>
<td>Safe</td>
<td></td>
</tr>
<tr>
<td>EFV-101-H</td>
<td>Closed</td>
<td>Target will not fill; High flow may have caused valve to close</td>
<td>Safe</td>
<td>H2 line may have leak</td>
</tr>
</tbody>
</table>
### ELECTRO-PNEUMATIC VALVES

<table>
<thead>
<tr>
<th>Valve</th>
<th>Status</th>
<th>Description</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP-D2PURGE</td>
<td>Open</td>
<td>Rough pump would pump on D2 tubing</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-D2PURGE</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-RUFVLVD</td>
<td>Open</td>
<td>Rough pump evacuates target vacuum jacket</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-RUFVLVD</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-FORVLVD</td>
<td>Open</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-FORVLVD</td>
<td>Closed</td>
<td>Forepump wouldn't pump on diffusion pump, diffusion pump would not operate</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-HVACD</td>
<td>Open</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-HVACD</td>
<td>Closed</td>
<td>Diffusion pump can not pump on target vacuum jacket</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-H2PURGE</td>
<td>Open</td>
<td>Rough pump would pump on H2 tubing</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-H2PURGE</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-RUFVLVH</td>
<td>Open</td>
<td>Rough pump evacuates target vacuum jacket</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-RUFVLVH</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-FORVLVH</td>
<td>Open</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-FORVLVH</td>
<td>Closed</td>
<td>Forepump wouldn't pump on diffusion pump, diffusion pump would not operate</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-HIVACH</td>
<td>Open</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>EP-HIVACH</td>
<td>Closed</td>
<td>Diffusion pump can not pump on target vacuum jacket</td>
<td>Safe</td>
</tr>
</tbody>
</table>

### FILTERS

<table>
<thead>
<tr>
<th>Filter</th>
<th>Status</th>
<th>Description</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-01-N</td>
<td>Plugged</td>
<td>Air is not supplied to pneumatic valves from the air compressor</td>
<td>Safe</td>
</tr>
</tbody>
</table>

### MANUAL VALVES

<table>
<thead>
<tr>
<th>Valve</th>
<th>Status</th>
<th>Description</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>MV-101-D</td>
<td>Open</td>
<td>Normal operating position during target fill</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-101-D</td>
<td>Closed</td>
<td>D2 cylinder not supplying gas for target fill</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-103-D</td>
<td>Open</td>
<td>Normal during fill</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-102-D</td>
<td>Closed</td>
<td>No D2 supplied to target</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-104-D</td>
<td>Open</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-104-D</td>
<td>Closed</td>
<td>D2 would not enter adsorber</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-105-D</td>
<td>Open</td>
<td>Contaminated D2 would enter target</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-105-D</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-106-D</td>
<td>Open</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-106-D</td>
<td>Closed</td>
<td>D2 would not exit adsorber</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-107-D</td>
<td>Open</td>
<td>D2 would vent, target would not fill</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-107-D</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-110-D</td>
<td>Open</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-110-D</td>
<td>Closed</td>
<td>PT-D2SUP would measure incorrect pressure</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-111-D</td>
<td>Open</td>
<td>Target D2 would vent, target would not fill</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-111-D</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-112-D</td>
<td>Open</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-112-D</td>
<td>Closed</td>
<td>PT-D2VENT would measure incorrect pressure, target control is inaccurate</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-113-D</td>
<td>Open</td>
<td>Target D2 would vent</td>
<td>Safe</td>
</tr>
<tr>
<td>MV-113-D</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
</tbody>
</table>

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.

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

**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 and 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**

<p>| 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 |</p>
<table>
<thead>
<tr>
<th>SAFETY VALVES</th>
<th>Open/Close</th>
<th>Function</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV-101-D</td>
<td>Open</td>
<td>Deuterium is vented from supply</td>
<td>Safe D2 vents into tent; Flammable gas detector triggers tent exhaust fan; D2 is vented through ducting to the outdoors</td>
</tr>
<tr>
<td>SV-101-D</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-102-D</td>
<td>Open</td>
<td>Deuterium is vented from supply line</td>
<td>Safe D2 vents into tent; Flammable gas detector triggers tent exhaust fan; D2 is vented through ducting to the outdoors</td>
</tr>
<tr>
<td>SV-102-D</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-103-D</td>
<td>Open</td>
<td>Deuterium is vented from target through the vent line</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-103-D</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-104-D</td>
<td>Open</td>
<td>Deuterium is vented from cold trap</td>
<td>Safe Would typically only operate when the cold trap is isolated</td>
</tr>
<tr>
<td>SV-104-D</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-01-H</td>
<td>Open</td>
<td>Hydrogen is vented from supply</td>
<td>Safe H2 vents into tent; Flammable gas detector triggers tent exhaust fan; H2 is vented through ducting to the outdoors</td>
</tr>
<tr>
<td>SV-01-H</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-02-H</td>
<td>Open</td>
<td>Hydrogen is vented from supply line</td>
<td>Safe H2 vents into tent; Flammable gas detector triggers tent exhaust fan; H2 is vented through ducting to the outdoors</td>
</tr>
<tr>
<td>SV-02-H</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-03-H</td>
<td>Open</td>
<td>Hydrogen is vented from target through the vent line</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-03-H</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-04-H</td>
<td>Open</td>
<td>Hydrogen is vented from cold trap</td>
<td>Safe Would typically only operate when the cold trap is isolated</td>
</tr>
<tr>
<td>SV-04-H</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-01-N</td>
<td>Open</td>
<td>Pneumatic backup N2 gas supply is vented</td>
<td>Safe Air compressor supplies pneumatic valves</td>
</tr>
<tr>
<td>SV-01-N</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-02-N</td>
<td>Open</td>
<td>Pneumatic air is vented</td>
<td>Safe N2 pneumatic supply will continue to pressurize pneumatic lines</td>
</tr>
<tr>
<td>SV-02-N</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-01-V</td>
<td>Open</td>
<td>Vacuum would not be achieved</td>
<td>Safe Operational problem</td>
</tr>
<tr>
<td>SV-01-V</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-02-V</td>
<td>Open</td>
<td>Vacuum would not be achieved</td>
<td>Safe Operational problem</td>
</tr>
<tr>
<td>SV-02-V</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-101-V</td>
<td>Open</td>
<td>Vacuum would not be achieved</td>
<td>Safe Operational problem</td>
</tr>
<tr>
<td>SV-101-V</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
<tr>
<td>SV-102-V</td>
<td>Open</td>
<td>Vacuum would not be achieved</td>
<td>Safe Operational problem</td>
</tr>
<tr>
<td>SV-102-V</td>
<td>Closed</td>
<td>Normal operating position</td>
<td>Safe</td>
</tr>
</tbody>
</table>
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 P&I Diagrams to confirm valve/instrument function).

(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:

c. 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 21 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

Initiation:

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

Automatic Responses:

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.

Results of failure:

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

Initiation:

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

Automatic responses:

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

Results of failure:
Hydrogen/Deuterium gas will vent into the area outside where the cylinders are stored.

(4) Failure of H2/D2 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 any amount of hydrogen/deuterium available during such a leak.

(5) Failure of H2/D2 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.

**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.
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:

None.

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

NM4 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 gas shed 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 LN2 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 shed 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 is small compared to the volume of the building 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.

SEAQUEST HALL

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.

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.

It is unlikely that any significant hydrogen will escape from the tent as the system is built according to Fermilab Guidelines for LH$_2$ Targets. Thus 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. Small leaks will not present this hazard immediately and target performance will suffer before this amount of hydrogen or deuterium would leak out and be discovered.

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 Research 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 60-69 of the E906 Target Safety Report.
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).

\[
E = 1.0 \\
t = 0.003 \text{ in.} \\
P \\
R = 1.5 \text{ in.} \\
P = S_a E t / (R + 0.6t)
\]

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

$P = 37.6$ 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).

\[
P = 2S_a E t / (R - 0.4t)
\]

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

$P = 75.3$ 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).

\[ E = 1.0 \]
\[ t = 0.002 \text{ in.} \]
\[ P \]
\[ L = 1.5 \text{ in.} \]

\[ P = \frac{2S_aEt}{(L + 0.2t)} \]
\[ P = (2)(18,800)(1)(0.002)/[(1.5) + (0.2)(0.002)] \]
\[ P = 50.1 \text{ psid} \]

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:**

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Maximum Pressure</th>
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<tbody>
<tr>
<td>Circumferential</td>
<td>37.6 psid</td>
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<tr>
<td>Longitudinal</td>
<td>75.3 psid</td>
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<tr>
<td>Heads</td>
<td>50.1 psid</td>
</tr>
<tr>
<td><strong>MAWP</strong></td>
<td><strong>37.6 psid</strong></td>
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</table>

*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.

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

October 17, 1995
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, \( R = 1.5 \text{ inches} \)
\( t = 0.003 \text{ inches} \)

Also, \( c = 1.5 \text{ inches} \).

The bending moment can be calculated from Roark and Young, Table 3, case 1a. \( M = 2.16 \text{ in-lbs} \). 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:

\[ \text{Stress due to Table Motion} = \sigma = \frac{M}{I/c} = \frac{2.16}{(0.0318/1.5)} = 102 \text{ psi} \]

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.

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

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

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.
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(909) 393-2273

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

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

<table>
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<th>QUANTITY</th>
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<th>AMOUNT</th>
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Specification: T304 AMS-5513F

Size: 0.00200
Type: T302/304

Lot #: 864141
Mill Source: ALLEGHENY

Condition
Rockwell
Ultimate Tensile (psi)
Yield Strength @ .2% offset (psi)
Percent Elongated in 2 inches
Bend Test
ASTM Grain Size
Embrittlement Test

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<th>Si</th>
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</tbody>
</table>

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

R.F. Briggs, Jr.
Quality Manager

954351
THIN METAL SALES, INC.  
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P Fermilab  
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Batavia, IL 60510

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<td>5 lb</td>
<td>S47040</td>
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<td>0.003 x 24\frac{1}{2}&quot; T304 Annealed Stainless</td>
<td>5 lb</td>
<td>5 lb</td>
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Specification: T302 AMS-5516L  
Specification: T304 AMS-5513F  

Type: T302/304  

Size: 0.00300  

Mill Source: ALLEGHENY  

State# 862622

Condition  
Annealed

Tensile Strength (psi)  
88,000

Yield Strength @ .2% offset (psi)  
32,000

Percent Elongated in 2 inches  
45%

End Test  
OK

STM Grain Size  
OK

Impact Test  
OK

Chemical Composition

<p>| | | | | | | | | | | |</p>
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</table>

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

R.F. Briggs, Jr.  
Quality Manager

THIN METAL SALES, INC.
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 H₂ and D₂, the mass flow rate of the vaporizing H₂ or D₂ 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.

\[ K = M - [(M-1)(M+1-2m)]^{1/2} \]

\[ M = 2.0, \ m = 0.5 \]

\[ K = 0.586 \]

\[ S = \pi R^2[1+K^2(2-K)] \]

\[ S = 10.5 \text{ sq. in.} \]

\[ A = 2\pi RL + 2S \]

\[ A = 195 \text{ in}^2 = 1.35 \text{ ft}^2 \]

\[ Y = \frac{2}{3}\pi KR^3 \]

\[ Y = 4.14 \text{ in}^3 \]

\[ V = \pi R^2L+2Y \]

\[ V = 139 \text{ in}^3 = 2.28 \text{ liters} \]
Required Mass Flow Rate:

\[ q = 3500 \text{ Btu/(hr-ft}^2) \]
\[ S = 1.35 \text{ ft}^2 \]
\[ Q \]
\[ \Delta H' = 434.2 \text{ J/g} \]
\[ \Delta H'' = 314.6 \text{ J/g} \]
\[ m' \]
\[ Q = q'S \]
\[ Q = 4725 \text{ Btu/hr} = 1384 \text{ W} \]
\[ m' = Q/\Delta H \]
\[ m'(H_2) = 3.2 \text{ g/s} = 25 \text{ lbs/hr} \]
\[ m'(D_2) = 4.4 \text{ g/s} = 35 \text{ lbs/hr} \]

Required Relief Valve Orifice:

\[ W(H_2) = 25 \text{ lbs/hr} \]
\[ W(D_2) = 35 \text{ lbs/hr} \]
\[ T = 530 ^\circ \text{R} \]
\[ M(H_2) = 2.0 \]
\[ M(D_2) = 4.0 \]
\[ Z = 1.0 \]
\[ K = 0.816 \]
\[ P_1 = 25.7 \text{ psia} \]
\[ C = 356 \]
\[ A \]
\[ A = W(TZ)^{1/2}/CKP_1(M)^{1/2} \]
\[ A(H_2) = 0.055 \text{ in}^2 \]
\[ A(D_2) = 0.053 \text{ in}^2 \]

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)

\[ W \]
\[ P_1 = 25 \text{ psia} \]
\[ P_2 = 15 \text{ psia} \]
\[ M(H_2) = 2.0 \]
\[ M(D_2) = 4.0 \]
\[ T = 530 ^\circ \text{R} \]
Z = 1
A = 0.110 sq. in.
K = 0.816
k = 1.404
m'  
Compressibility
Valve Orifice Area
Valve Coefficient of Discharge
Ratio of Specific Heats
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.

\[ \rho(H_2) = 0.00216 \text{ g/cc} \]
\[ \rho(D_2) = 0.00375 \text{ g/cc} \]
\[ \mu(H_2) = 1.25 \times 10^{-5} \text{ g/cm-s} \]
\[ \mu(D_2) = 1.55 \times 10^{-5} \text{ g/cm-s} \]
\[ v \]
\[ f \]
\[ D = 1.02 \text{ cm} \]
\[ \varepsilon = 0.0015 \text{ mm} \]
\[ \Delta P_1 \]
\[ L = 91.4 \text{ cm} \]
\[ m'(H_2) = 6.15 \text{ g/s} \]
\[ m'(D_2) = 8.64 \text{ g/s} \]
\[ \text{Re} = \rho v D / m = 4m'/D \pi \mu \]
\[ \text{Re}(H_2) = 6.14 \times 10^5 \gg 2300, \text{ therefore, Turbulent.} \]
\[ \text{Re}(D_2) = 6.96 \times 10^5 \gg 2300, \text{ therefore, Turbulent.} \]
\[ f(H_2) = 0.0146 \quad (\text{From Moody Chart, } \varepsilon/D = 0.000147) \]
\[ f(D_2) = 0.0145 \quad (\text{From Moody Chart, } \varepsilon/D = 0.000147) \]

\[ v = 4m'/\pi \rho D^2 \]
\[ v(H_2) = 3484 \text{ cm/s} \]
\[ v(D_2) = 2820 \text{ cm/s} \]
ΔP = ρv^2fL/2D
ΔP1(H_2) = 1715 Pa = 0.25 psi
ΔP1(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:

\[ q' = 3500 \text{ Btu/(hr-ft}^2) = 1.1 \text{ W/cm}^2 \]
\[ A = \pi(0.5 \text{ in})(42 \text{ in}) = 66 \text{ in}^2 = 426 \text{ cm}^2 \]
\[ Q = 467 \text{ W} \]
\[ m'(H_2) = 6.15 \text{ g/s}; \Delta h = Q/m' = 76 \text{ J/g} \]
\[ m'(D_2) = 8.64 \text{ g/s}; \Delta h = Q/m' = 54 \text{ J/g} \]
\[ h_1(H_2) = 198.5 \text{ J/g} \]
\[ h_1(D_2) = 196.9 \text{ J/g} \]
\[ h_2(H_2) = 198.5 + 76 = 275 \text{ J/g} \]
\[ h_2(D_2) = 196.9 + 54 = 251 \text{ J/g} \]
\[ T(H_2) = 29 \text{ K} \]
\[ T(D_2) = 37 \text{ K} \]

Heat Flux to Uninsulated Tube
Outside Surface Area of Tube
Heat Transfer to Tube
Energy Increase of Hydrogen
Energy Increase of Deuterium
Saturated Vapor Enthalpy of H_2
Saturated Vapor Enthalpy of D_2
Enthalpy of H_2 at Relief Valve
Enthalpy of D_2 at Relief Valve
Temperature of H_2 at Relief Valve
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.

\[ \rho(H_2) = 0.8479 \text{ E-3 g/cc} \]
\[ \rho(D_2) = 0.169 \text{ E-2 g/cc} \]
\[ \mu(H_2) = 1.53 \text{ E-5 g/cm-s} \]
\[ \mu(D_2) = 2.14 \text{ E-5 g/cm-s} \]
\[ v \]
\[ f \]
\[ D = 1.02 \text{ cm} \]
\[ \varepsilon = 0.0015 \text{ mm} \]
\[ \Delta P2 \]
\[ L = 107 \text{ cm} \]
\[ m'(H_2) = 6.15 \text{ g/s} \]
\[ m'(D_2) = 8.64 \text{ g/s} \]

\[ \text{Re} = \frac{ρvD}{μ} = 4m'/Dπμ \]
\[ \text{Re}(H_2) = 5.02 \times 10^5 \gg 2300, \text{ therefore, Turbulent.} \]
\[ \text{Re}(D_2) = 5.04 \times 10^5 \gg 2300, \text{ therefore, Turbulent.} \]
\( f(H_2) = 0.015 \) (From Moody Chart, \( \varepsilon/D = 0.000147 \))
\( f(D_2) = 0.015 \) (From Moody Chart, \( \varepsilon/D = 0.000147 \))

\[
v = 4m' \pi \rho D^2 \\
v(H_2) = 8876 \text{ cm/s} \\
v(D_2) = 6257 \text{ cm/s}
\]

\[
\Delta P = \rho v^2 fL/2D \\
\Delta P_{2(H_2)} = 5256 \text{ Pa} = 0.76 \text{ psi} \\
\Delta P_{2(D_2)} = 5206 \text{ Pa} = 0.76 \text{ psi}
\]

**Total Pressure Drop in Line:**
\[
\Delta P_{\text{total}(H_2)} = \Delta P_1 + \Delta P_2 = 1.01 \text{ psi} \\
\Delta P_{\text{total}(D_2)} = \Delta P_1 + \Delta P_2 = 1.04 \text{ psi}
\]

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 71-72 of the E906 Target Safety Report.
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.

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

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

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

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.

\[ D_{0} = 5.0 \text{ in.} \quad \text{Outer Shell Diameter} \]
\[ L = 15.5 \text{ in.} \quad \text{Length of Shell} \]
\[ t = 0.125 \quad \text{Shell Thickness} \]
\[ A \quad \text{Factor Obtained from Fig. 5-UGO-28.0} \]
\[ B \quad \text{Factor Obtained from Fig. 5-UNF-28.30} \]
\[ P \quad \text{Max. Allowable External Pressure} \]
\[ E = 10.0 \text{ E6 psi} \quad \text{Modulus of Elasticity} \]

March 6, 1995
Cylindrical Shell, External Pressure (cont.):

\[ D_0 / t = 40 > 10 \] therefore, use UG-28(c,1).

Step 1: \( L / D_0 = 3.1; \ D_0 / t = 40. \)
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:

\[ P = 4Bt / 3D_0 \]
\[ P = (4)(7500)(0.125)/[(3)(5.0)] \]
\[ P = 250 \text{ psid} \]

Maximum Allowable Working Pressures:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>--------</td>
<td>250 psid</td>
</tr>
<tr>
<td>Shell, Circumferential</td>
<td>321 psid</td>
<td>--------</td>
</tr>
<tr>
<td>Shell, Longitudinal</td>
<td>677 psid</td>
<td>--------</td>
</tr>
<tr>
<td>MAWP, External</td>
<td>--------</td>
<td>250 psid</td>
</tr>
<tr>
<td>MAWP, Internal</td>
<td>321 psid</td>
<td>--------</td>
</tr>
</tbody>
</table>

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 LH2 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 74-85 of the E906 Target Safety Report.
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.

\[ S_u = 121,100 \text{ psi} \]
\[ S_y = 107,000 \text{ psi} \]
\[ q = 15 \text{ psid} \]
\[ E = 13.4 \times 10^6 \text{ psi} \]
\[ \nu = 0.3 \]
\[ a = 2.25 \text{ inches} \]
\[ t \]
\[ y \]

Minimum Ultimate Strength
Minimum Yield Strength
Actual pressure applied to window
Minimum Modulus of Elasticity
Poisson's ratio
Window radius
Window thickness
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, \( t_{\text{calculated}} \), is equal to 0.0055.

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

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:**

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

\(\sigma_{edge} = 26,570 \text{ psi}\)

**Stress at Center:**

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

\(\sigma_{center} = 43,560 \text{ psi}\)

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. H₂/D₂ will be vented outdoors.
3. The initial level of H₂/D₂ 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.

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

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

Sold Fermi Labs
P.O. BOX 500 Acct. Dept.
Batavia, IL 60510

To

Ship
Receiving Dept.
Kirk & Batavia Roads

TOTAL CONTACT:

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  Quantity Shipped  Description
        Complete

85710   C     1 Lot (3.0 lbs.)  15-3-3 Titanium, Annealed

          .0055 x 10.125 x as rolled width x coil
          AMS 4914 with standard AEDo exceptions

CHEMICAL ANALYSIS

<table>
<thead>
<tr>
<th>No. — Lot No.</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Al</th>
<th>Fe</th>
<th>Y</th>
<th>Va</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6230H</td>
<td>.011</td>
<td>.11</td>
<td>2.6</td>
<td>2.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td>Va</td>
<td>Ti</td>
</tr>
</tbody>
</table>

*DENotes LESS THAN

PHYSICAL PROPERTIES

<table>
<thead>
<tr>
<th>Lot No.</th>
<th>Yield Strength</th>
<th>Tensile Strength</th>
<th>Elong %</th>
<th>Hardness</th>
<th>Grain Size</th>
<th>Yield Strength</th>
<th>Tensile Strength</th>
<th>Elong %</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6230H</td>
<td>107,000</td>
<td>121,100</td>
<td>14.3%</td>
<td>15T915</td>
<td>ASTM#6.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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
APPLICATION ENGINEER

FORM ARM-632-43-006
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

SAE Technical Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences.
The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement
arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be reaffirmed, revised, or cancelled. SAE invites your
written comments and suggestions.

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2.2 ASTM Publications:


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>
<thead>
<tr>
<th>Element</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vanadium</td>
<td>14.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Chromium</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Tin</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Iron</td>
<td>--</td>
<td>0.25</td>
</tr>
<tr>
<td>Oxygen</td>
<td>--</td>
<td>0.13</td>
</tr>
<tr>
<td>Carbon</td>
<td>--</td>
<td>0.05</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>--</td>
<td>0.05 (500 ppm)</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>--</td>
<td>0.015 (150 ppm)</td>
</tr>
<tr>
<td>Residual Elements, each (3.1.1)</td>
<td>--</td>
<td>0.10</td>
</tr>
<tr>
<td>Residual Elements, total (3.1.1)</td>
<td>--</td>
<td>0.40</td>
</tr>
<tr>
<td>Titanium</td>
<td>remainder</td>
<td></td>
</tr>
</tbody>
</table>

3.1.1 Determination not required for routine acceptance.

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

3.2.1 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 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 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 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

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>102 - 137 ksi (703 - 945 MPa)</td>
</tr>
<tr>
<td>Yield Strength at 0.2 % Offset</td>
<td>100 - 126 ksi (689 - 869 MPa)</td>
</tr>
<tr>
<td>Elongation in 2 Inches (50.8 mm) or 4D</td>
<td>12%</td>
</tr>
</tbody>
</table>

3.5.1.1.1 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

<table>
<thead>
<tr>
<th>Nominal Thickness Inch</th>
<th>Nominal Thickness Millimeters</th>
<th>Bend Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 0.070, incl</td>
<td>Up to 1.78, incl</td>
<td>4</td>
</tr>
<tr>
<td>Over 0.070 to 0.125, incl</td>
<td>Over 1.78 to 3.18, incl</td>
<td>5</td>
</tr>
</tbody>
</table>

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 Resampling and Retesting:
(R)
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 Identification:
(R)
Shall be in accordance with AMS 2809.

5.2 Packaging:

5.2.1 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.
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 87-90 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
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 LH2
   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.
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 LH2 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.
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-talkie. 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 LH2 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.
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 LH2 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.
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 Target Enclosure and Ventilation

0.1 Description

On the basis of the ongoing discussion on the target enclosure and the respective ventilation system to be utilized in E906, this note basically focuses on the estimation of the pressure drop across the target enclosure ventilation ducting as well as the approximate timing information of venting hydrogen and deuterium from the enclosure in case of any leakage during operation. Also, assuming the installed ducting is guided to the infinite volume towards the top in the hall, a critical radius is calculated outside of which there will be negligible chance of causing a fire hazard by any escaped hydrogen through the ventilation.

The enclosure of the target here refers to the volume surrounded by the concrete blocks on the sides and the top and a curtain with holes for the beam and the ventilation in the front (upstream). The ventilation system is expected to have a 10 inch diameter vent ducting made of sheet metal which will be installed and guided from the top of the curtain to the outside volume towards the roof inside the hall. The estimated length of the ducting is \( \sim 13 \text{ ft} \) (\( \sim 8 \) to \( 10 \text{ ft} \) vertically towards the roof) depending on the availability of space. A fan, controlled with a logic controller, will be used which will be triggered by any slight hazardous conditions such as, high target insulating vacuum pressure coupled with low target temperature, detection of hydrogen or deuterium by the flammable gas detector located inside the enclosure etc. The fan will have a capacity of 1300 cfm air for our ducting system. A very rough schematic of the system is shown in Fig. K1.

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. Few numbers in the calculations are very standard and the same procedure followed by E866 has been adopted as far as practicable.

0.1.1 Pressure Drop Across the Enclosure Ventilation Ducting:

The ventilation system is schemed as \( \sim 12 \text{ ft} \) of 10 inch diameter commercial steel piping with one regular 45° elbow. The following relevant quantities 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 = $\frac{Q}{\pi(D^2)}$ = 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:

$$\Delta P = \left[ f \left( \frac{L + (L_e)^2}{D} \right) \cdot \frac{V^2}{2} + g z \right] \cdot \rho_{air} \quad (0.1.1)$$

Now putting all the respective values, we obtain $\Delta P$ = 0.21 inches of H$_2$O. 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.

0.1.2 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 $\times$ 76in $\times$ 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 Hydrogen = $\frac{M_{D_2}}{m_{D_2}}$ = 7.32 s

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

$$t_{H_2} = \frac{V_{H_2}}{1300} = 3.2s, \quad (0.1.2)$$

$$t_{D_2} = \frac{V_{D_2}}{1300} = 3.9s, \quad (0.1.3)$$
\[ t_{encl} = \frac{V_{encl}}{1300} = 28s, \quad (0.1.4) \]

where \( t_{H_2/D_2/encl} \) is the time required to vent \((H_2/D_2/\text{air})\) once the fan is turned on at \( t = 0 \) s. Now 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), we can conclude that the 1300 cfm fan can decently vent the system in case of any target flask failure and, hence the safety requirements are sufficiently fulfilled. Note that, due to the very similar system characteristics in both E866 and E906, most of the quantities that have been used in this model are standard and same as used in E866.

**0.1.3 Estimation of a Critical Distance Inside the Hall:**

In case of a target flask rupture and venting the escaped \( H_2/D_2 \) through the ducting towards the infinite volume inside the Hall (we use the term *infinite* to emphasize the fact that the volume inside the hall is immensely large compared to the volume of the leaked \( H_2 \) or \( D_2 \)), it is necessary to model a volume shape and calculate the distance \((r)\) within which there could be a risk of fire hazard due to the leakage. Considering the outlet of the vent system as the center of a spherical volume which corresponds to the escape point of \( H_2 \) and the amount of volume required by \( H_2 \) to be 150 m\(^3\) at room temperature, the radius of the spherical volume can be estimated. We consider the amount of space available inside the hall for the escaped \( H_2 \) to be 1/4 th of the sphere. However, when the \( H_2 \) comes out of the vent as a result of any leakage during the experiment, it is already mixed with air and hence, diluted. An estimation of this dilution can be made by taking into the ratio of the volume of the \( H_2 \) into the target enclosure and the volume of the air inside the enclosure itself. It turned out that due to the large volume of the enclosure, the effective volume of the space that the leaked \( H_2 \) would require is approximately 10\% of the real volume (150 m\(^3\)). Hence,

\[
\left( \frac{4}{3}\pi r^3 \right) \frac{1}{4} = 15
\]

\[ \Rightarrow r = 2.5m \quad (0.1.5) \]

As we all know, the diffusion rate of \( H_2 \) in air is immensely fast, we can assure that anything beyond the above estimated radius is safe as far as any fire hazard is concerned. Now it is to be checked and determined if there is anything within the radius of 2.5 m inside the hall that could cause any ignition and hence, potential fire hazard.
Alternative venting scheme

There is another provision to vent the hydrogen from the target enclosure from the hall to outside. This can be realized with same kind of ducting in the hall that starts from the enclosure and it uses the existing hole in the roof just on the top of the entrance to the beam area. The pipe (right from the hole) in the hall to outside is approximately 40 ft. We will use a 10 inch diameter piping from the enclosure to the hole and then 6 inch diameter inside the existing pipe to outside. There will be a regular 90° elbow between the enclosure and the hole inside the hall.
Inside the hall,

- \( L = \) Length of the pipe = 20 ft
- \( D = \) Diameter of the pipe = 0.833 ft

In this case, the pressure difference between the enclosure and the hole is:

\[
\Delta P = \left[ f \left( \frac{L + (L_e)t}{D} \right) \cdot \frac{V^2}{2} + gz \right] \cdot \rho_{air} \tag{0.1.7}
\]

which comes out to be 0.26 inches of H₂O.

From the hole to the outside of the hall,

- \( L = \) Length of the pipe = 40 ft
- \( D = \) Diameter of the pipe = 0.5 ft

In this case, the pressure difference between the outside and the hole is 2.8 inches of H₂O. Note that this drop is with respect to the pressure at the inlet i.e. at the beginning of the hole inside the hall where there already exists a pressure difference as calculated above with respect to the pressure in the enclosure.
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 97 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 Hydrogen 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 1.1 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 shed 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 shed 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 101-107 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 Material Tensile Test Results

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<thead>
<tr>
<th>Sample #</th>
<th>Width (inches)</th>
<th>Cross Section (sq. in.)</th>
<th>Break Point (pounds)</th>
<th>Tensile (psi)</th>
<th>Break Type</th>
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<tbody>
<tr>
<td>1</td>
<td>0.494</td>
<td>0.000988</td>
<td>103.6</td>
<td>104858</td>
<td>base mat'l at edge of overlap</td>
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<tr>
<td>2</td>
<td>0.516</td>
<td>0.001032</td>
<td>103</td>
<td>99806</td>
<td>base mat'l away from joint</td>
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<tr>
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<td>0.506</td>
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<td>99.7</td>
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<td>base mat'l away from joint</td>
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<td>94545</td>
<td>base mat'l away from joint</td>
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<tr>
<td>5</td>
<td>0.512</td>
<td>0.001024</td>
<td>96.1</td>
<td>93848</td>
<td>base mat'l away from joint</td>
</tr>
</tbody>
</table>

Test A - 1/2" overlap of 0.002" thick T304 Annealed Stainless Steel

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Width (inches)</th>
<th>Cross Section (sq. in.)</th>
<th>Break Point (pounds)</th>
<th>Tensile (psi)</th>
<th>Break Type</th>
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<td>0.001036</td>
<td>99.3</td>
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</table>

Test B - One piece sample of 0.002" thick T304 Annealed Stainless Steel

<table>
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<tr>
<th>Sample #</th>
<th>Width (inches)</th>
<th>Cross Section (sq. in.)</th>
<th>Break Point (pounds)</th>
<th>Tensile (psi)</th>
<th>Break Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>0.48</td>
<td>0.00144</td>
<td>135.6</td>
<td>94167</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>0.491</td>
<td>0.001473</td>
<td>137.5</td>
<td>93347</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>0.481</td>
<td>0.001443</td>
<td>132.3</td>
<td>91684</td>
<td></td>
</tr>
</tbody>
</table>

Test E - One piece sample of 0.003" thick T304 Annealed Stainless Steel

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Width (inches)</th>
<th>Cross Section (sq. in.)</th>
<th>Break Point (pounds)</th>
<th>Tensile (psi)</th>
<th>Break Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>0.504</td>
<td>0.001512</td>
<td>139</td>
<td>91813</td>
<td>base mat'l away from joint</td>
</tr>
<tr>
<td>40</td>
<td>0.51</td>
<td>0.00153</td>
<td>136</td>
<td>88934</td>
<td>base mat'l away from joint</td>
</tr>
<tr>
<td>41</td>
<td>0.506</td>
<td>0.001518</td>
<td>136</td>
<td>89869</td>
<td>joint seam</td>
</tr>
<tr>
<td>42</td>
<td>0.51</td>
<td>0.00153</td>
<td>138</td>
<td>90350</td>
<td>joint seam</td>
</tr>
<tr>
<td>43</td>
<td>0.508</td>
<td>0.001524</td>
<td>137</td>
<td>90053</td>
<td>base mat'l at edge of overlap</td>
</tr>
</tbody>
</table>
TEST 1 - .5" OVERLAP (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 109-112 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. LN₂ 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 114 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 H₂/D₂ 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.
INTERLOCK SYSTEM TEST

Each interlock will be tested and documented for operability with a safety personnel on hand to witness its safe operation.

L. SAFETY CORRESPONDENCE

To be determined

M. CALL-IN LIST

Chiranjib Dutta
Wolfgang Lorenzon
Kazutaka Nakahara
Richard Raymond
Wang Su-Yin