Jefferson Lab Tritium Target Cell

David Meekins
November 28, 2014

1 Overview

The JLab Tritium Target is expected to be used for a number of approved experiments (see Refs (1) (2) (3) (4)) starting in the Fall of 2015 at Jefferson Lab Continuous Electron Beam Accelerator Facility (CEBAF). The target consists of 5 cells of various species of gas installed in place of the standard Hall A cryogenic target. Several solid targets will be hung below the cells. Each of the cells will be filled to the required fill pressure and valved and capped off. The cells are thus considered to be sealed. The gaseous fluid will not be circulated marking a departure from the normal Hall A target operation.

The target will operate in three modes as shown in the table below.

Mode	Temperature	Purpose
Warm standby mode	Room temp (300K)	Standby no beam operation
Cool down mode	50K to 300K	Cool down of system (temporary condition)
Run mode	50K	Normal Run mode. Beam on target is only allowed in this mode.

The target cells will be filled to various pressures depending on the fill gas as indicated in the table below:

Target	Fill Gas	Pressure at (300K)	Maximum Beam Current μA
Empty	N/A	0 psia	10
Tritium	Tritium (T2)	200 psia	20
Helium 3	^{3}He	400 psia	25
Deuterium	^{2}H	400 psia	25
Helium	^{4}He	400 psia	25

The cells will be attached to a heat sink cooled by the End Station Refrigerator (ESR) and maintained at 50K by a heater controlled by a PID.

2 Requirements

The design of the cell must meet both physics and pressure safety requirements. While the operational pressure of the cell is 200 psi, the fill design pressure must be 1000 psi to match the pressure relief of the fill station at SRS/SRNL. The cell walls must be thin enough to allow the passage of both the beam and the scattered particles of interest. To meet both requirements tight fitting covers installed for shipping and filling have been designed so that the cell walls are acceptably thin for operations at 200 psi and a more than adequate factor of safety is available for shipping and filling. With these covers installed, the cell shall survive a 10ft drop without damage to the thin sections.

The beam passing through the aluminum walls also generates heat that must be removed. This shall be accomplished by cooling the target cell with the End Station Refrigerator (ESR). The beam also generates large backgrounds at the entrance and exit of the cell (thin sections known as windows). The thinner these sections are the less background that is generated. Materials used in the cell construction must be compatible with tritium, 12 GeV 25 µA electron beam and cryogenic service.

3 Design

The design of the tritium cell builds on the JLAB experience of liquid hydrogen and gas helium cryogenic targets. Extensive use of Aluminum alloys (Al 7075, Al 6061, and Al 2219) has been made in many geometries. Aluminum ConFlat (CF) joints have allowed the used of Al 7075 cells. These cells can be fabricated with thin sections for use with design (working) pressures exceeding 200 psi in certain geometries. The summary pressure design is discussed below as are the specific materials to be used in fabrication and assembly.

The overall design is shown in the Figures below:

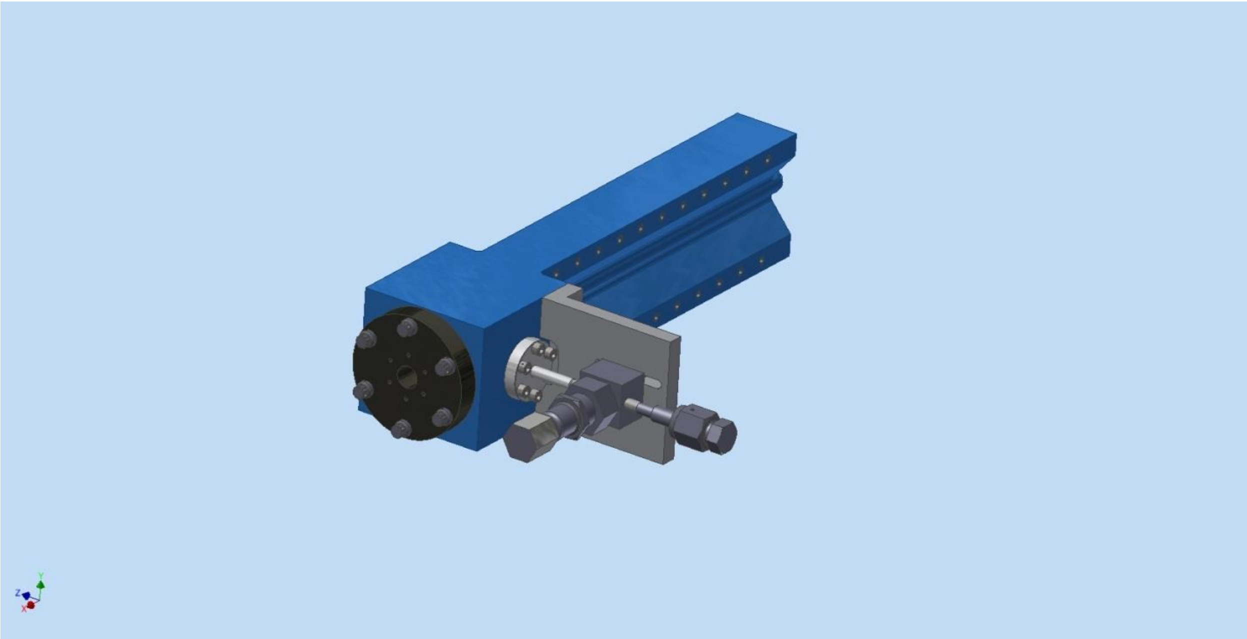

Figure 3-1: Cell Assembly as viewed from upstream side

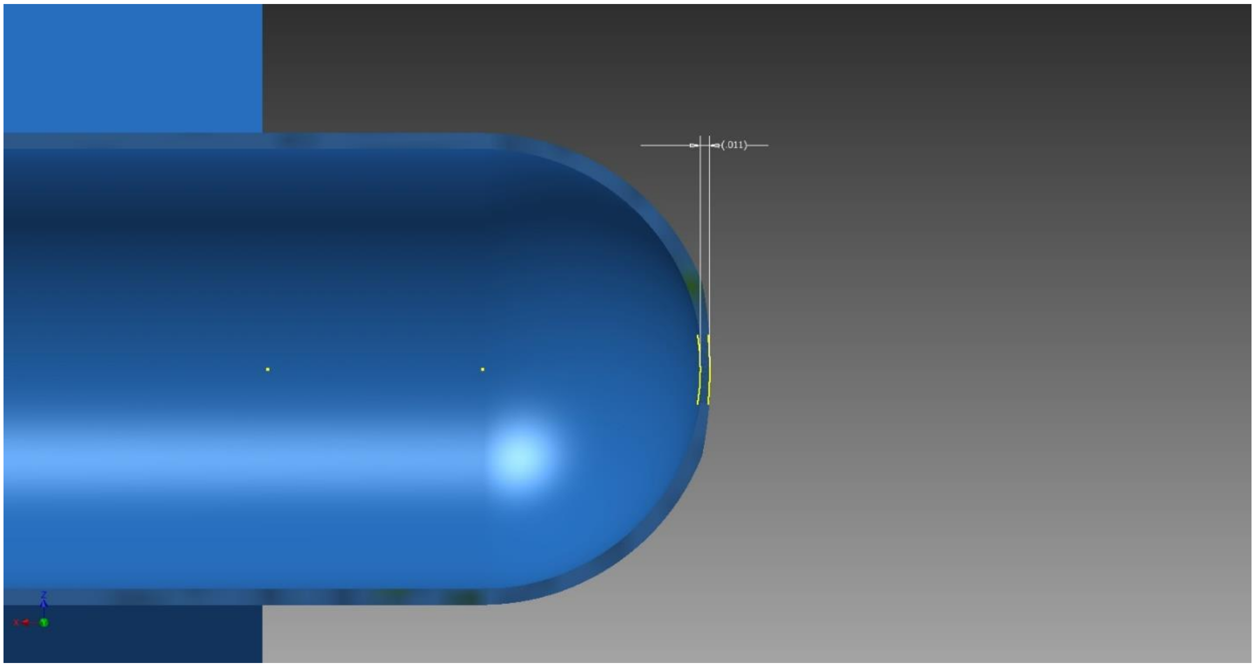

Figure 3-2: Cell exit window showing thinned section. Nominal thickness is 0.018 inch at thinned section thickness is 0.011 inch.

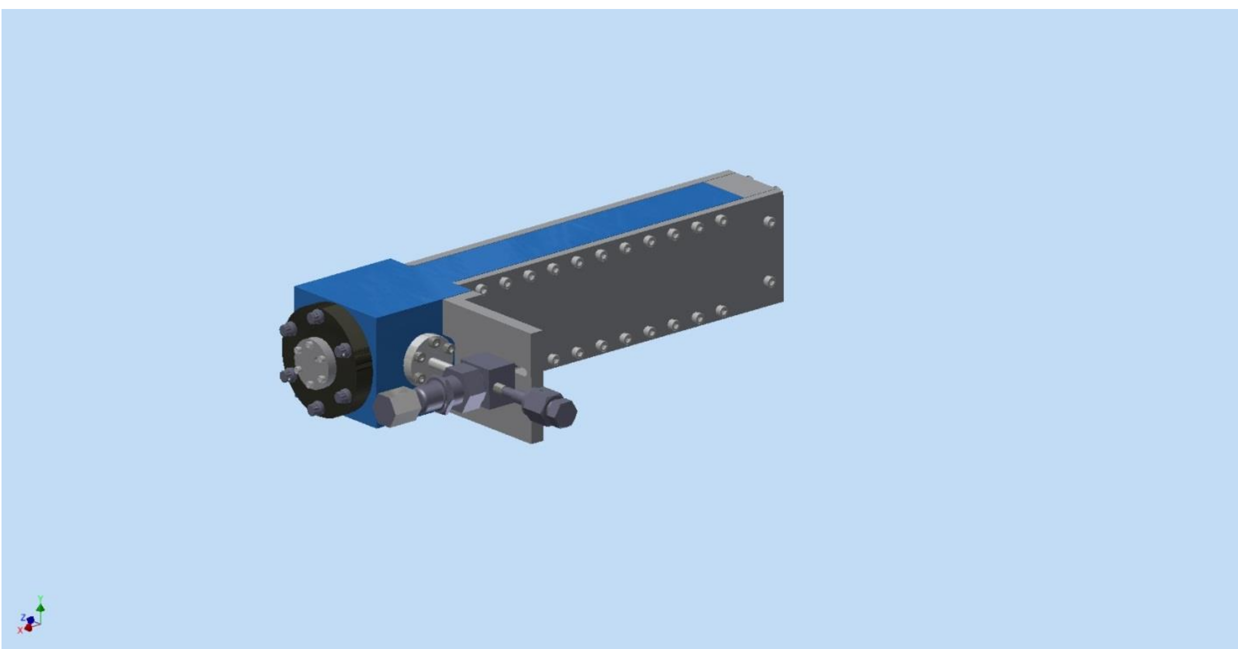

Figure 3-3: Cell Assembly as viewed from upstream with shipping/filling coverrs installed

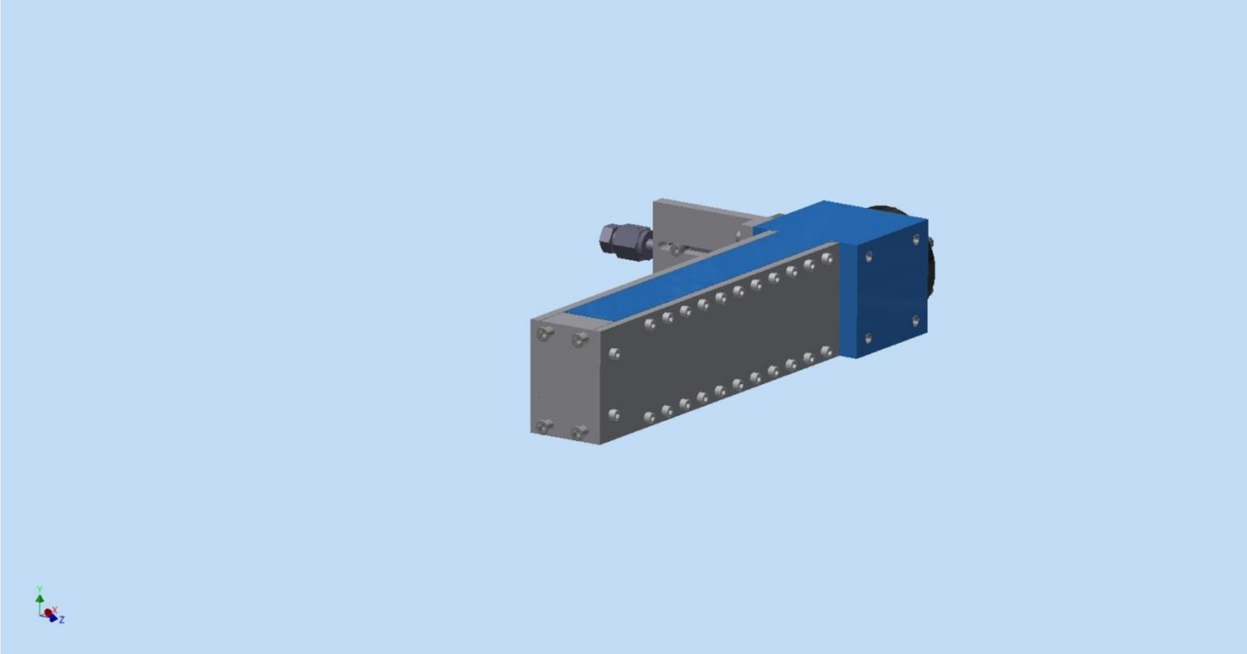

Figure 3-4: Downstream view of cell assembly with covers installed.

The cell assembly consists of four main components: 1) the cell main body, 2) the cell entrance window, 3) the fill tube and 4) the shipping/filling covers. Details of the design may be found in JLAB Drawings listed in the table below:

JLAB Drawing Number	Description
TGT-103-1000-0013	Cell Assy Shipping/Filling Config
TGT-103-1000-0010	Cell Main Block Assy
TGT-103-1000-0011	Fill Tube Assy
TGT-103-1000-0012	Cell Assy as Used in Beam
TGT-103-1000-0100	Entrance window
TGT-103-1000-0101	Main Body
TGT-103-1000-0103	Valve Support Bracket
TGT-103-1000-0105	1.33 CF Flange to ¼ Tube
TGT-103-1000-0106	Exit Window Cover
TGT-103-1000-0109	Entrance Window Plug/Cover
TGT-103-1000-0110	Side Cover

3.1 Materials

The cell main body and entrance tube is fabricated from Aluminum 7075-T651 plate (ASTM B209). The fill tube, and flange are fabricated from ASTM A240 SST 304/304L plate. The valve is a Swagelok SS-4BW-BW4-C5-SC11 (modified to have a nut on the actuator) stainless steel 316L ASTM A479. The valve is attached to the fill tube via GTAW butt weld. Weld coupons from the fill tube material and filler metal shall be impact tested (weld metal, HAZ, and base metal) at -325F. Swagelok lists the valve working pressure maximum at 100 psi (5). This coupled with a hand calculation shows that the component is under low stress when installed and operated at JLAB. We will exercise JLAB policy (Ref (6)) to use ASME VIII D1 UHA 51(g) (see Ref (7)) to exempt the material of the valve from impact testing.

3.2 Pressure design

The cell assembly without shipping/filling covers has three main components. For the operational design pressure of 200 psi the design is adequate. Hand calculations and FEA both indicate a suitable safety margin (i.e. above 10). Burst testing yields a safety factor of nearly 15.

Filling and shipping present different challenges. During shipping and handling the cell must be safeguarded from impact loading. The filling process has a system relief set point of 1000 psi necessitating a cell design pressure of 1000 psi. To meet these requirements shipping/filling covers have been designed. Analysis and testing of this final assembly has not been completed as parts are still in fabrication.

JLAB shall provide detailed analysis and testing data to SRS/SRNL in all formats required for the safety basis. It is requested that a detailed list of SRS/SRNL requirements be provided to JLAB as soon as reasonably possible.

3.3 Testing

All assembled cells shall be pressure/leak tested with helium in reverse mode. He leaks shall not be observed above 10^{-9} atm cc/s. A test pressure of 500 psi shall be held for 30 minutes. Testing shall be witnessed by the responsible engineer and performed by a trained technician.

3.3.1 Prototype Cells

Prototype cells have undergone hydrostatic proof testing to destruction. The burst pressures for the entrance windows are above 2900 psi. The burst pressures for the main bodies are above 3400 psi. The tests were conducted without the shipping/filling covers. These covers are expected to raise the burst pressures well above 5000 psi. Testing with covers installed is scheduled for January 2015.

4 Tritium Filling and Recovery

The current proposal to fill and recover the tritium from the cell is based on SRS/SRNL performing this work. JLAB shall not “handle” the tritium gas. The does require special attention to shipping the filled cell.

5 Cooling

The electron beam at JLAB will interact with the tritium gas and with the thin sections of the aluminum 7075 cell. This interaction results in heat deposited in the cell and the tritium fluid. While the heating in the tritium fluid is negligible, the beam heating of the thin aluminum sections will be about 11W. This heat must be removed. The cells are attached to a temperature stabilized heat sink which is actively cooled using 15K helium gas from the End Station Refrigerator (ESR) (see Figure 5-1 below). The return gas from the heat sink shall be mixed with bypass He gas at 15K to ensure a return temperature below 30K. The expected flow through the entire circuit is less than 5 g/s.

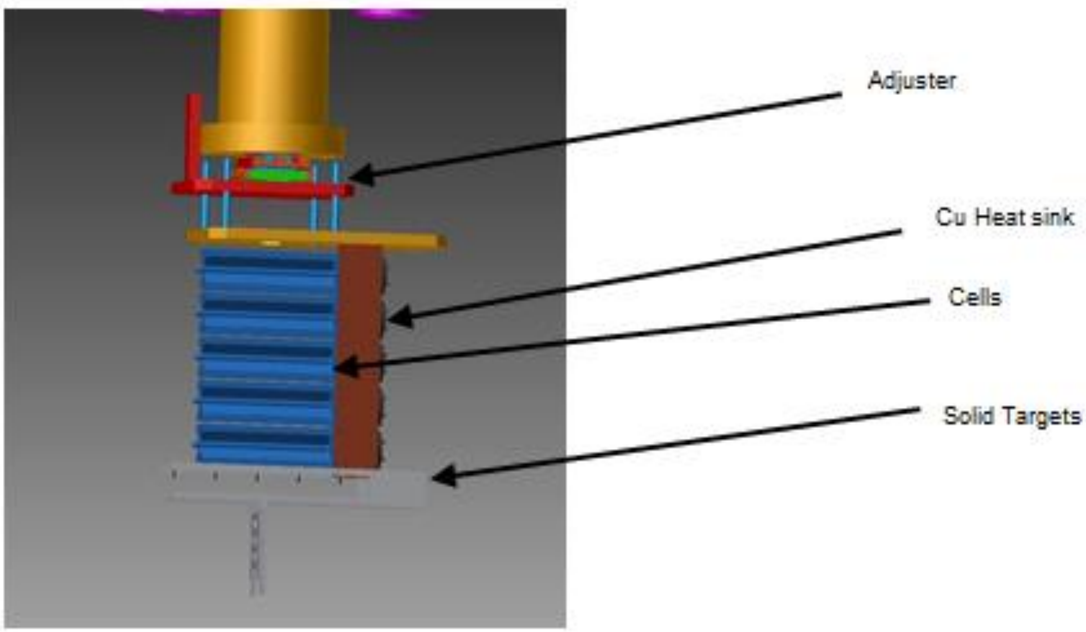

Figure 5-1: Target Stack

The normal operating temperature of the heat sink shall be maintained between 35K and 45K. Beam heating has been modeled using ANSYS. A maximum cell temperature (in the local area of the beam spot only) is expected to be about 112K (see Figure below).

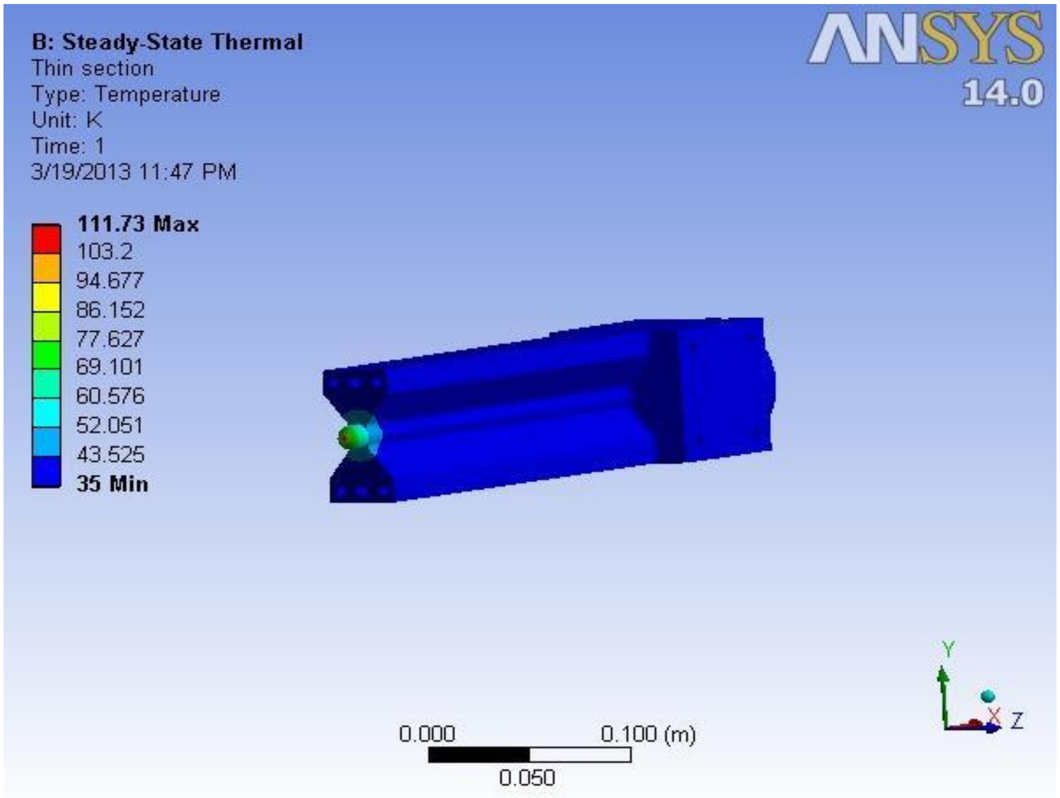

Figure 5-2: Thermal model showing beam heating affects with 25μA beam current

6 Tritium Permeation

Tritium permeation through the thin sections of the cell wall is expected. Calculations estimating the amount of permeation through the cell walls are shown in Reference (8). In summary, the rate of tritium permeation through the cell is expected to be about 5 x 10^{-9} Ci/s. Over the span of one year the total loss of tritium would be about 0.142 Ci.

7 Cell Activation

The electron beam will activate the aluminum and alloying elements in the AL 7075 cell. This activation was calculated using a FLUKA model and summarized in a report by JLAB (9). The expected dose at 30 cm for various decay times is shown in the table below.

Time after beam operations	Dose mrem/h
0h	3
1 month	0.3
1 year	0.1

The main contribution to the expected dose rate is from the following isotopes: ^{65}Zn, ^{51}Cr, ^{7}Be, ^{57}Co, ^{58}Co.

8 Beam and tritium induced embrittlement

The cell may be affected by beam and tritium induced embrittlement. This is summarized in Ref (10). The onset of beam induced embrittlement is not expected below aluminum temperatures of 180K and is thus not considered to be an issue. Tritium embrittlement is also not expected at these pressures and temperatures. However, studies are planned between JLAB and SRS/SRNL to examine the short term effects of tritium on this aluminum alloy at elevated pressures and temperatures (10).

9 Cell Handling

9.1 Filling/Recovery

Both filling and recovery operations are expected to take place at SRS/SRNL (12). After the recovery operation is complete the metal cell shall be considered waste.

9.2 Shipping

The cell will be filled with a maximum of 1099 Ci of tritium. Thus a type A container may be used. While Jefferson Lab is a licensed receiver it is not able to ship this quantity. Additional assistance from SRS/SRNL will be requested.

9.3 Installation and Removal

Handling of the cell outside of the shipping container by JLAB personnel shall be limited to installation and removal only. These activities shall be performed by fully trained personnel with Hall A in controlled access while all non-essential personnel are prohibited entrance. The shipping container shall be placed inside a dedicated tritium handling hut with forced air ventilation to the tritium stack. The cell may only be transferred from or to the shipping container to or from the scattering chamber while the hut is in position and the ventilation is on. Installation shall be the last task prior to closing the scattering chamber. Removal shall be the first task after opening the scattering chamber. Detailed procedures shall be reviewed and followed.