Overview of Fabrication Techniques and Lessons Learned With Accelerator Vacuum Windows

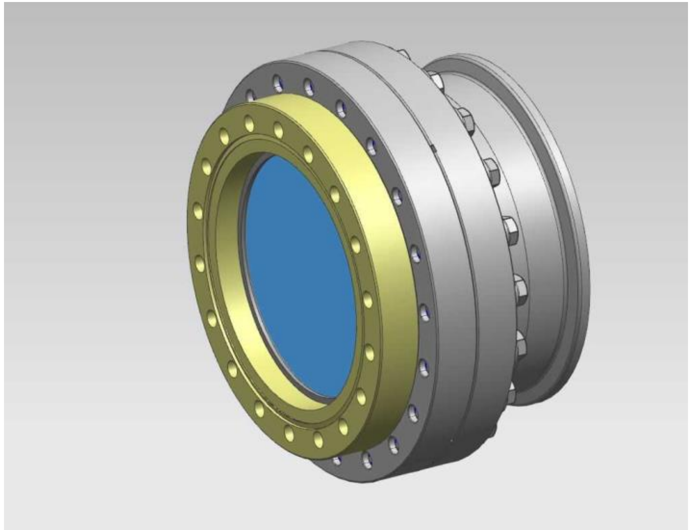
Christine Ader

IPAC 2018

30 April 2018

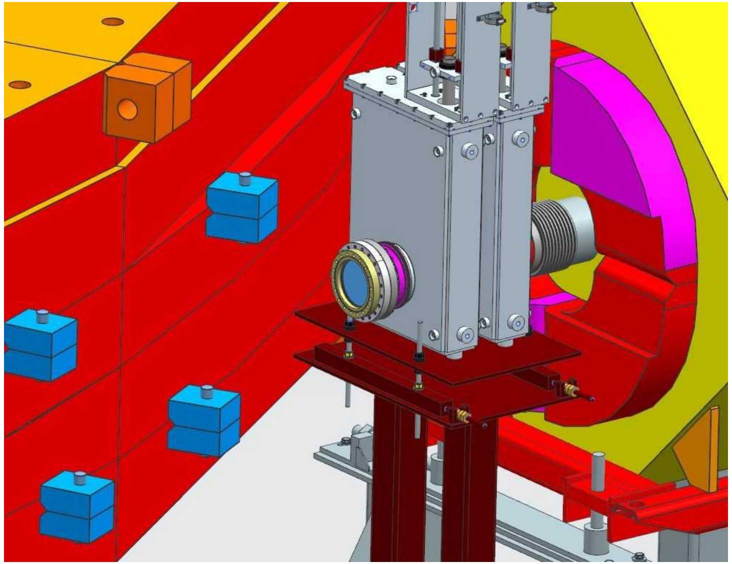
Agenda

1. Definition
2. History and Operations
3. Design
4. Fabrication
5. Failures
6. Future Work
7. Conclusion



Vacuum Window Definition

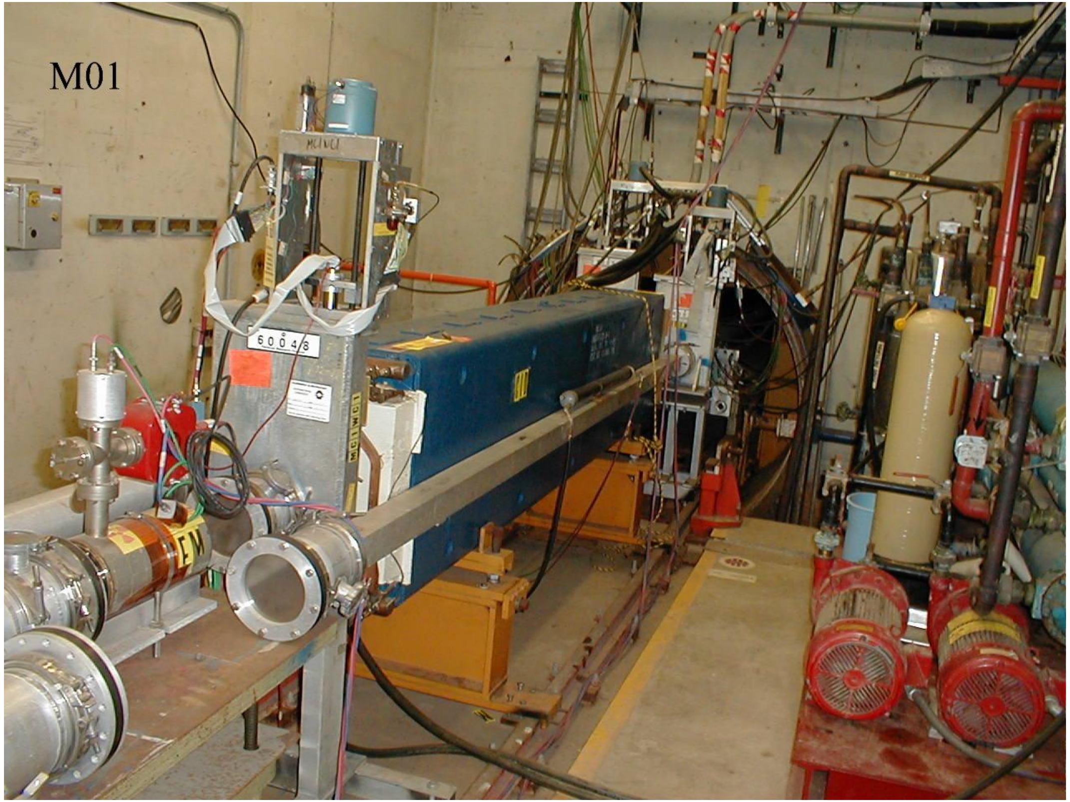
- Any relatively thin separation between a volume under vacuum and a volume at atmospheric pressure or vacuum through which primary or secondary beam passes
- Can also be a thin separation between atmosphere and a pressurized gas
- Can used to allow to place instrumentation into the beam line
- Used at the end of beam lines before a target or beam absorber
- Windows can also partition different vacuum sectors (i.e., one sector has ion pumps and another has roughing pumps)



History and Operations

- Vacuum windows have been a part of Fermi since the first beam line was commissioned
- This is an example of an aluminum quick disconnects with o-rings

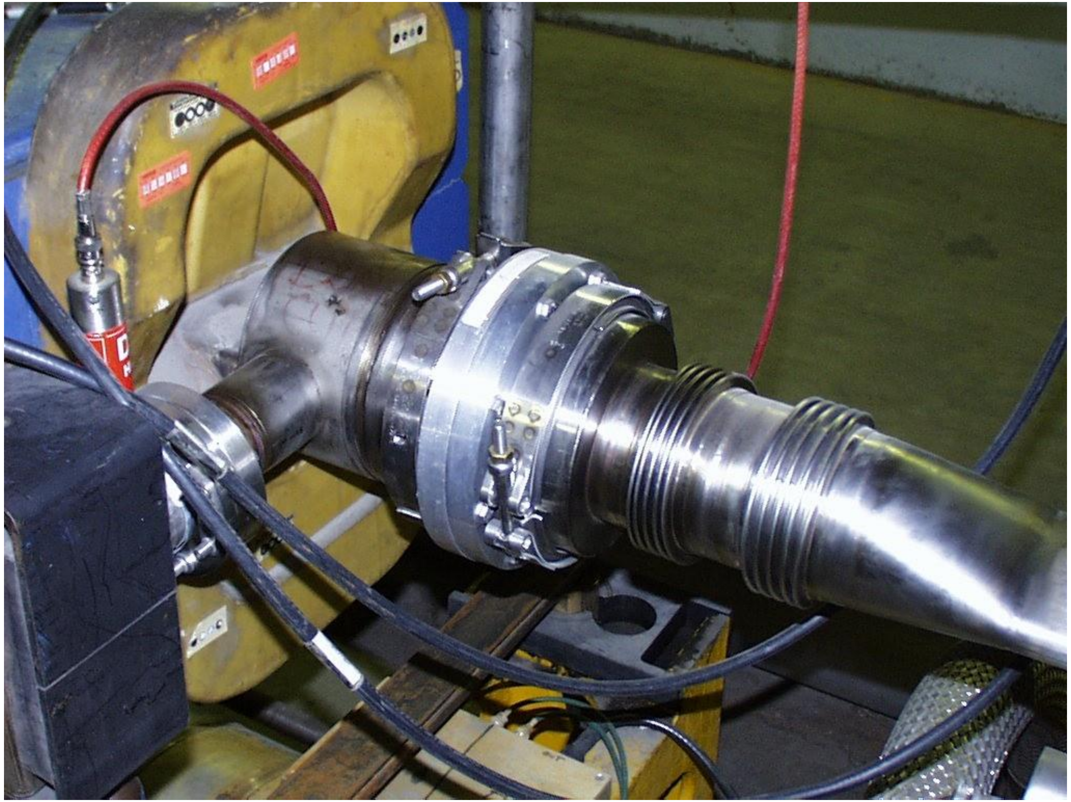
History and Operations, cont.



- This shows 4 vacuum windows
- Vacuum windows allow instrumentation to be moved in and out of the beamline quickly without opening up vacuum

Vacuum-to-Vacuum Windows

- Vacuum windows can separate vacuum sectors which have different vacuum pressures
- In this area, there are sectors using ion pumps and others using turbo pumps



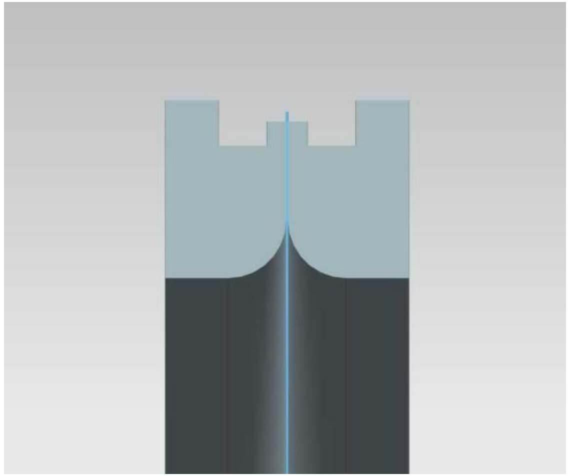
Fermilab

Design Criteria

- Purpose
- Thickness
- Material Requirements
- Vacuum Constraints
- Thermal Requirements: 100 C nominal air temperature
- Cyclic
- Corrosion (i.e., nitric acid and ozone concentrations in the air)
- Radiation
- Safety: FESHM 5033.1: Vacuum Window Safety

Design of Joint is Critical

- Best joints take into consideration load can come from either direction
- Symmetrical joint design with no sharp edges is best
- Furnace vacuum brazing or Electron-beam welding are the typical fabrication techniques
- Joint clearance on furnace braze joints needs to specified
- Depth of penetration on EB joint samples may need to be completed



Fermilab

Roark's and Young

Roark's 6th Ed. analytical solutions obtained first to proceed:

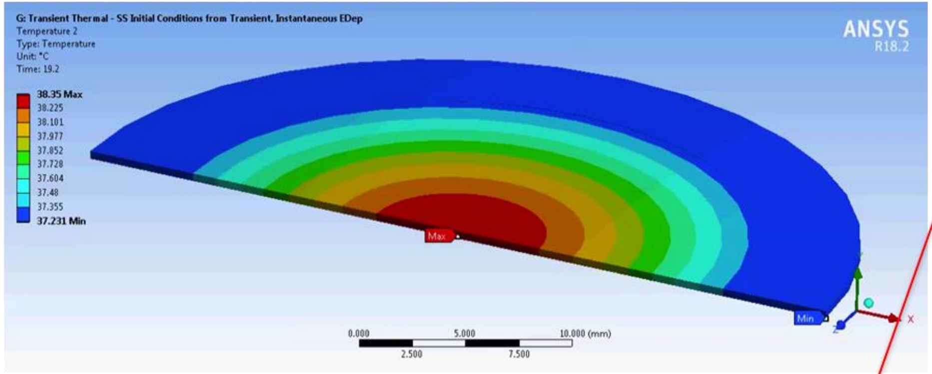
$$\frac{qa^4}{Et^4} = K_1 \frac{y}{t} + K_2 \left(\frac{y}{t}\right)^3 \qquad (11.11\text{-}1)$$

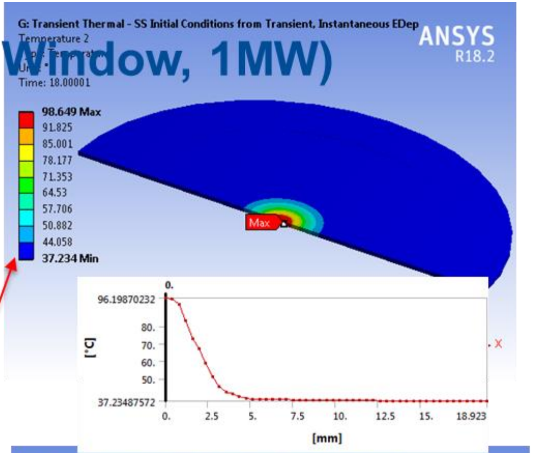
$$\frac{\sigma a^2}{Et^2} = K_3 \frac{y}{t} + K_4 \left(\frac{y}{t}\right)^2 \qquad (11.11\text{-}2)$$

3. Fixed and held. Uniform pressure q over entire plate.	$K_1 = \frac{5.33}{1-\nu^2}$	$K_2 = \frac{2.6}{1-\nu^2}$	
	(At center)	$K_3 = \frac{2}{1-\nu}$	$K_4 = 0.976$
	(At edge)	$K_3 = \frac{4}{1-\nu^2}$	$K_4 = 1.73$
			(Refs. 15 and 16)

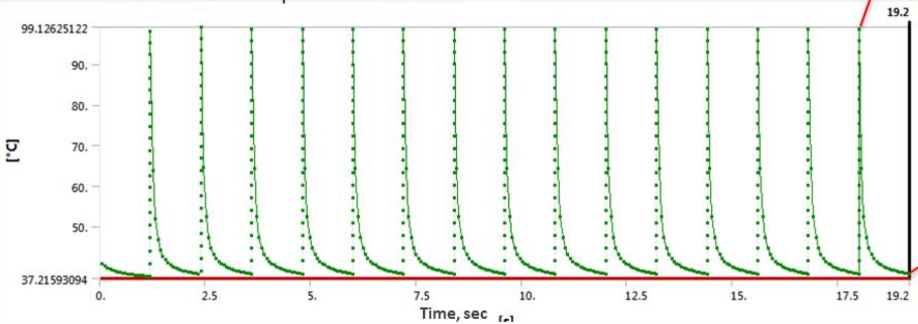
Transient Thermal FE Analysis (.015in Be Window, 1MW)

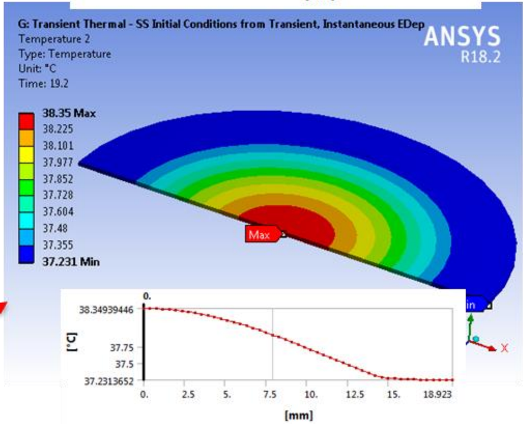
Be Window Transient Thermal Temperature Results





Be PF60 Window Max Temperature vs. Time



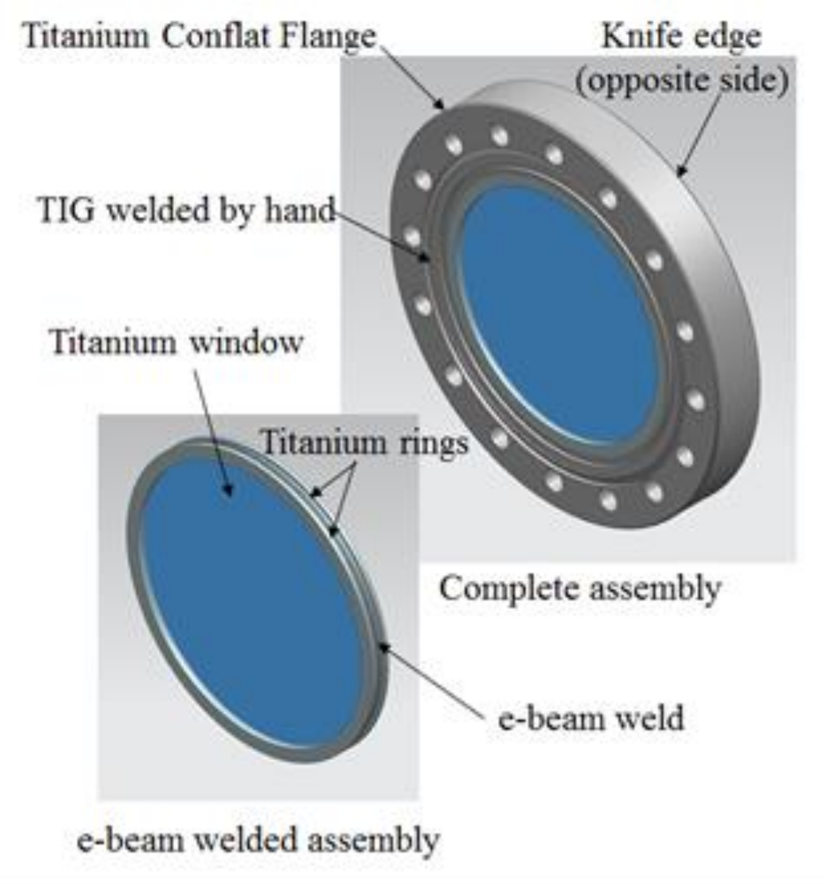


9 4/24/2018 Raul Campos | 1MW Beam NuMI Pre-Target Beryllium Vacuum Window

Fermilab

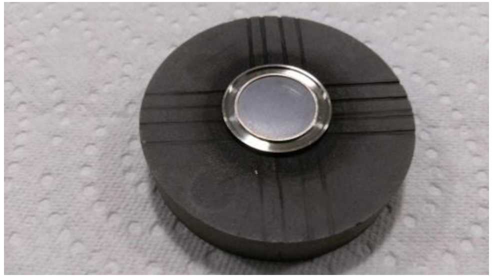
Electron-Beam Welded Window Assembly

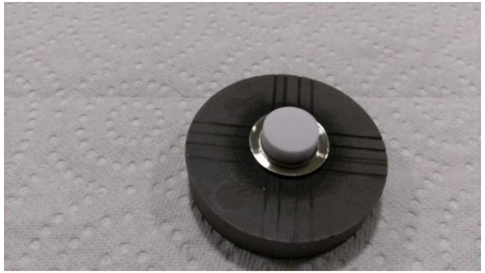
- The Grade 5 titanium foil is sandwiched between two Ti rings and EB welded
- This sub-assembly is cleaned and leak checked
- Then TIG-welded by hand to the Ti conflat, Grade 2

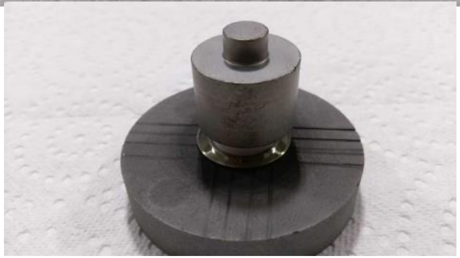


Fabrication of Brazed Beryllium Window*

- The parts are assembled before being put in the vacuum furnace oven
- The Beryllium window assemblies are made through a two-step vacuum furnace braze
- The temperature cycle for beryllium brazing is a soak at 650 ºC for ~15 minutes, with a final temperature of about 800 ºC maximum for seven minutes







*(Pictures courtesy of Omley Industries)

Window Failures

- Vacuum and light positive pressure load can be dangerous
- There are windows in the beam lines that have been operational for over 30 years
- Leaks of vacuum windows are rare, but the consequences can be high
- Serious failures can cause:
  - Equipment damage
  - Beam downtime
  - Personnel injury including potential hearing loss
  - Contamination if window is constructed of beryllium
  - Clean-up and manpower costs

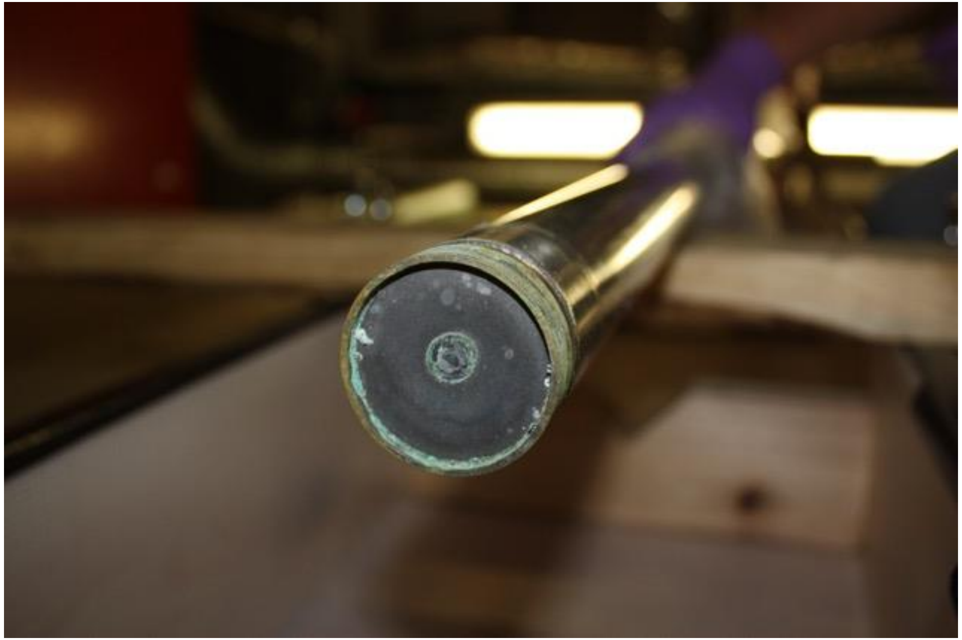
Beryllium Window in Proton Beamline for Pbar Production *

- Was in beam for about a year with a 0.3 mm RMS spot size ~5e12 protons/pulse
- Accumulated about 1.7E19 protons with no failures
- Can see spot where beam heating has caused oxidation
- A dropped wrench damaged a beryllium window at another location and after that incident, designs included a catcher (pair of Ti windows with air break which would limit spread of Be contamination upstream in case of catastrophic window failure

* Credit: Jim Hylen, NBI03, November 7-11, 2003, “FNAL thin beam windows”

NuMI Beam Line Beryllium Vacuum Window Failure

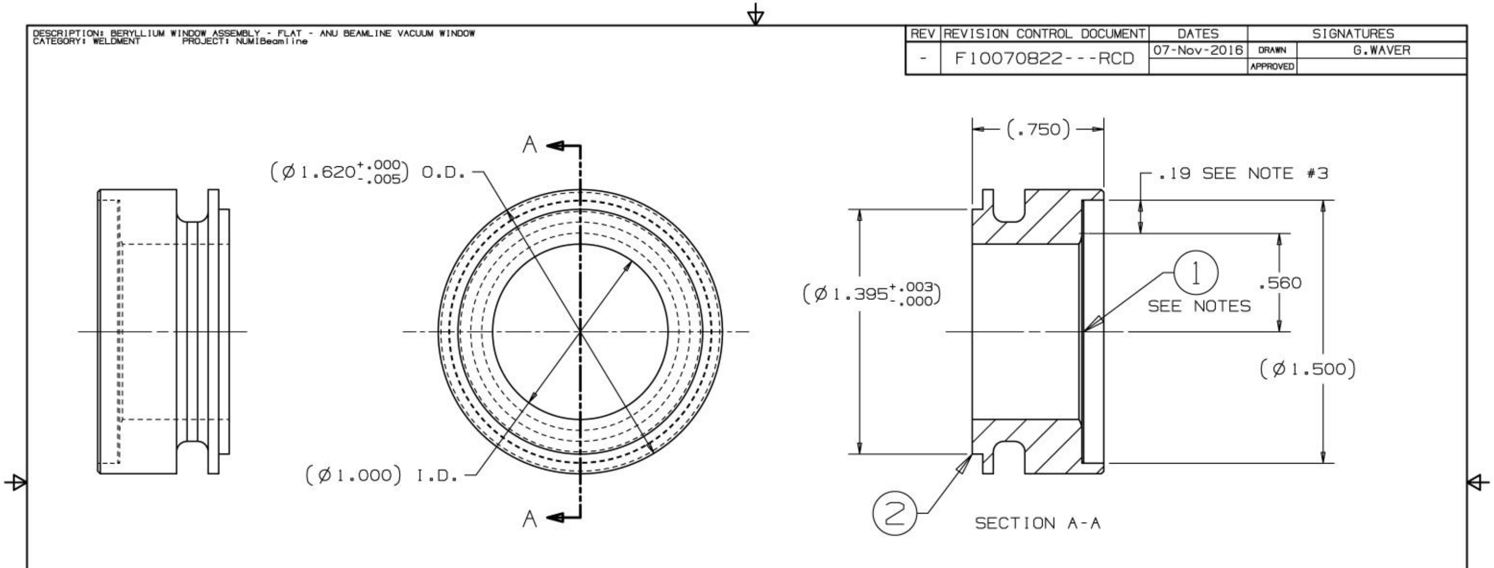
- This window failed after seven years and 7 x 10^7 pulses
- It developed a small 10^{-8} permeation vacuum leak in the outer braze area most likely due to corrosion from the humid and nitric acid environment
- There is a greenish copper oxide on most of the outer braze joint
- But the pin hole leak can be seen on the outer diameter with a whitish corrosion surrounding it



Fermilab

DESCRIPTION: BERYLLIUM WINDOW ASSEMBLY - FLAT - ANU BEAMLINE VACUUM WINDOW
CATEGORY: WELDMENT PROJECT: NUMIBeamline

REV	REVISION CONTROL DOCUMENT	DATES	SIGNATURES	
-	F10070822---RCD	07-Nov-2016	DRAWN	G.WAVER
			APPROVED	



NOTES:

1. BRAZE MATERIAL COPPER/SILVER/TIN IS ACCEPTABLE
2. BRAZE TO BE VACUUM LEAK TIGHT- NO LEAK DETECTABLE ON MOST SENSITIVE SCALE OF A HELIUM LEAK DETECTOR WITH A MINIMUM SENSITIVITY OF 10E-9 ATM.CC/SEC.
3. BRAZE ALLOY BOND BETWEEN SS AND Be FOIL MUST BE CONTINUOUS AND COVER THIS RADIAL ZONE. MINIMUM CLEAR APERTURE SHALL BE Ø3/4".

ITEM	PART NO.	DESCRIPTION	QTY.
2	F10070819	BE WINDOW HOLDER - FLAT	1
1	F10070820	BE WINDOW - FLAT	1

UNLESS OTHERWISE SPECIFIED

±.X	±.XX	±.XXX	±X/X	±X°
.1	.010	.005	1/16	1/2°

BREAK ALL SHARP EDGES .015 MAX.
DO NOT SCALE DRAWING
DIMENSIONS BASED ON ASME Y14.5-2009
MAX. ALL MACH SURFACES 125
DRAWING UNITS: INCHES

DRAWN	G.WAVER	DATE	07-Nov-2016
CHECKED		DATE	
APPROVED		DATE	

USED ON: F10071732

MATERIAL: SEE PARTS LIST

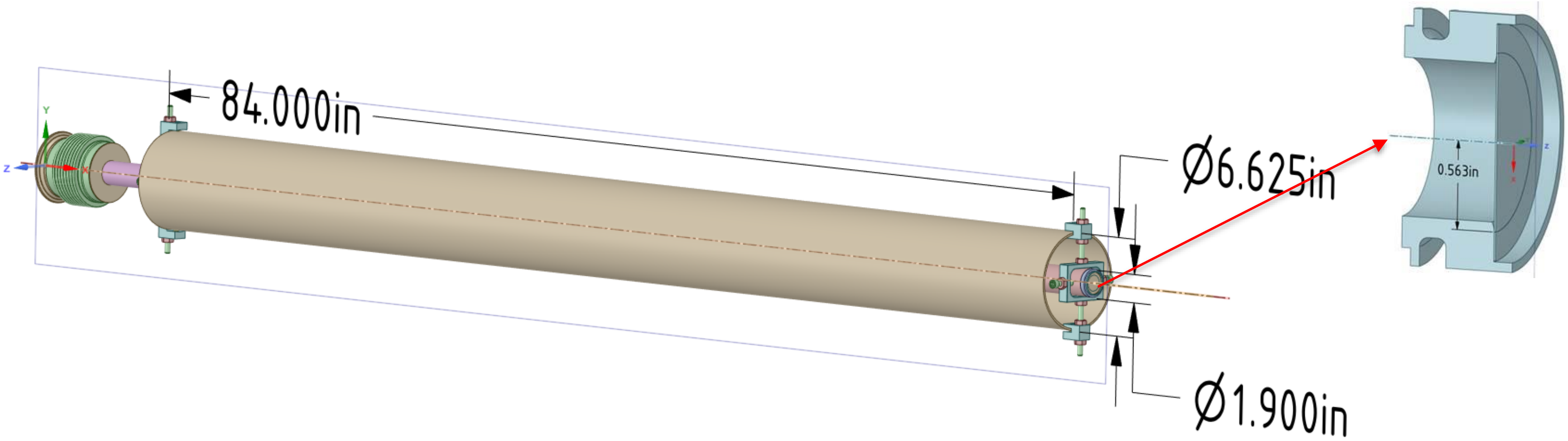
GROUP: Accelerator Mechanical Support — CAGE CODE: 0U5R6

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

NAME: BERYLLIUM WINDOW ASSEMBLY - FLAT

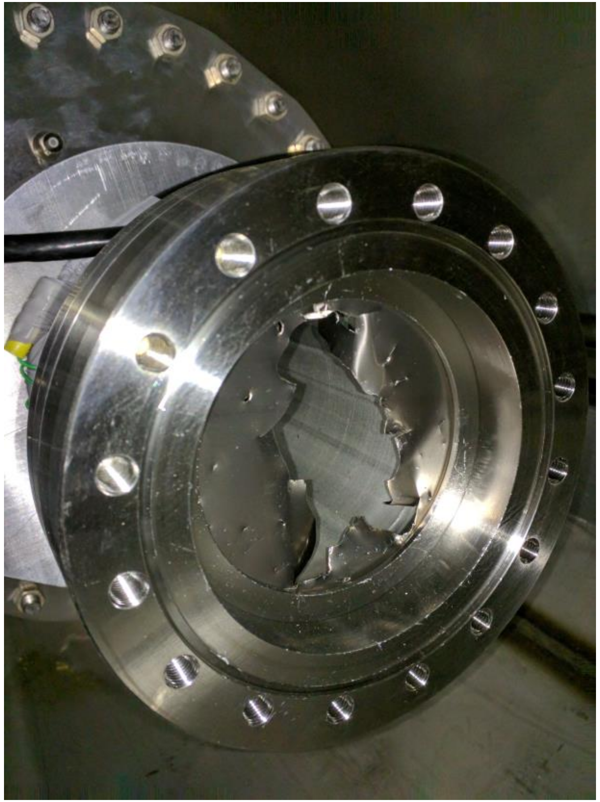
SCALE	SIZE	DRAWING NUMBER	SHEET	REV
1:1	B	F10070822	1 OF 1	-

Beam Tube Assembly – Baseline (700kW beam) Design



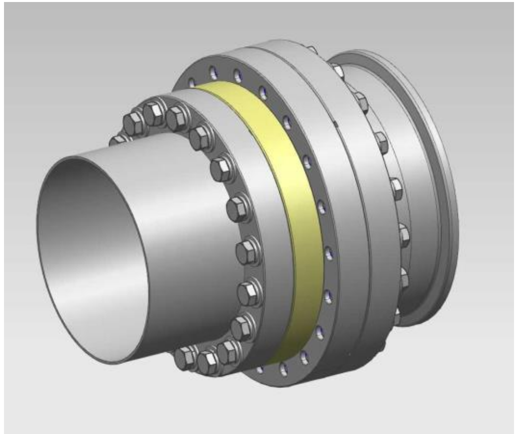
* Graphics from Raul Window and Comparison with 0.010in Thick Baseline Design," April 24, 2018 presentationCampos, "1MW Beam NuMI Pre-Target Beryllium PF60 Vacuum Window – Thermal and Structural Finite Element Analyses of 0.015 in Thick

Example of a Titanium Window Failure



- Another older titanium window failed because of the design created a stress concentration which over time caused the window to shear
  - That window was used both as a functional part to separate the vacuum from atmosphere while allowing the beam to pass through but also as a gasket
  - That window was sandwiched between some type of knife edge which clearly deformed the titanium to the point where a distinct indentation was created

Safety Implementation



- Safety features which should be used:
  - Yellow caution sign
  - Yellow danger tape around window
  - Protective covers during work
  - Add shroud if possible
    - One Be window was damaged because a wrench was dropped and then hit a window
  - Screens/shielding around air gaps
  - Consider a titanium backup window for a beryllium window
    - Use of Be raises toxicity/mixed waste/safety concerns

Safety Implementation, cont.

- This window is at the end of the running g-2 experiment
- Window was covered during work in the area

Fermilab

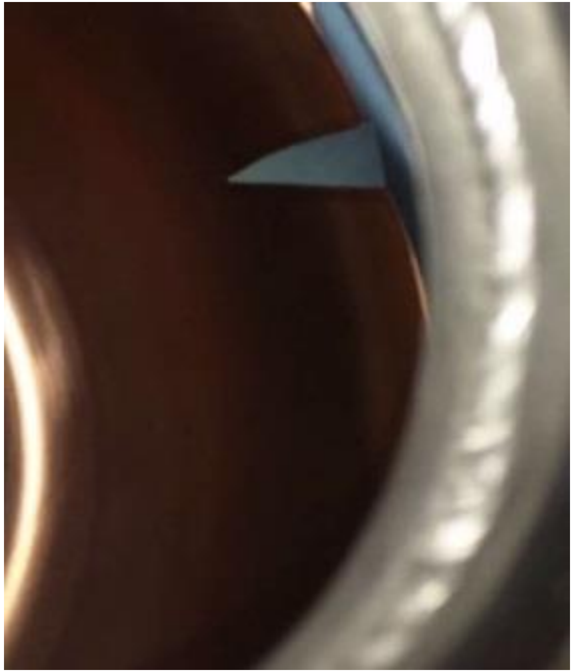
Future Work on Vacuum Windows: Pre-forming Windows During Fabrication to Reduce Stresses

- Most windows start out flat, Small dish in the window is produced during the brazing process from gravity and from the leak checking process
- With the application of pressure they become very tight and quickly reach a point of plastic deformation (If the material has good ductility, it strain relieves, and the stress is limited)
- The NuMI Beam line window had an initial deformation of the window of about .020” which came from the brazing operation
- The dishing or pre-forming reduces the stresses of a given load and why failure is higher than calculated and the deflection per load is approximately 1/2 of the flat disc calculations

Future Work: Brittle Materials

Beryllium windows have brittle versus failures

- Can create shrapnels which can be projected into the air
- Beryllium contamination consequences can be severe
- Can include inhalation of Beryllium dust and/or particles which can cause Chronic Beryllium Disease (CBD): chronic and sometimes fatal lung condition
- Beryllium sensitization is a condition in which a person’s immune system may become highly responsive or allergic to the presence of any Beryllium within the body



Future Work: Investigate Coatings to Mitigate Corrosion

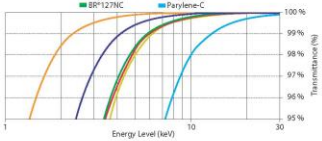
MATERION

TRANSMITTANCE

Materion Electrofusion Window Coating Transmittance Curves

Beryllium windows are an excellent means of isolating vacuum and/or other environments from air while allowing x-rays to pass through unrestricted. When used with inert or totally dry environments, beryllium windows can last almost indefinitely. In fact, actively cooled beryllium windows installed at synchrotron facilities, where neither side is exposed to atmosphere, have been in continuous service for over 15 years. However, if windows are used in less controlled environments, corrosion can occur quickly. Exposure to moisture or chlorides and sulfates (found in non-deionized water), could lead to corrosion in a matter of hours. This corrosion may eventually result in a system vacuum leak.

Transmittance of Various Coatings



Various anti-corrosion coatings are available to protect beryllium windows. The most common coatings used in x-ray applications are Parylenes (Impermion™; -N; -C), Epoxies (BR-127; BR-127NC), and Boron Hydride. Metal coatings, such as electroless nickel, aluminum, and gold are effective corrosion barriers, but may also inhibit x-ray transmittance. There are three main points to consider when choosing protective coatings for beryllium x-ray windows:

- Impact on x-ray transmittance
- Processing and operating temperatures
- Cost and lead-time

High temperature bakeouts, subsequent joining processes, and operating temperatures are also important factors affecting coatings. Temperature Performance for the coatings is as follows:

Coating	Max Temp in Air	Max Temp in Vacuum
BR-127	150 °C (300 °F)	150 °C (300 °F)
BR-127NC	150 °C (300 °F)	150 °C (300 °F)
Parylene-N	110 °C (230 °F)	240 °C (460 °F)
Parylene-C	130 °C (270 °F)	260 °C (500 °F)
Boron Hydride	350 °C (660 °F)	400 °C (750 °F)
Impermion	300 °C (570 °F)	450 °C (840 °F)

One should also consider how using any specific coating will impact budgets and schedules. We offer BR-127 and BR-127NC as quick-turn processed coatings and available at a relatively low cost. Parylene coatings add moderate cost and require additional lead time. Boron Hydride offers better transmissivity and temperature endurance, but is our most expensive coating offering and requires the longest lead time.

As depicted in the above transmittance graph, all coatings with the exception of Parylene-C have about the same x-ray transmittance above the 12keV energy range. However, consideration should also be given to the elements that comprise a coating. For example, Materion's Impermion has Fluorine, while Parylene-C has Chlorine, and BR-127 contains traces of heavier elements such as iron, chromium, and strontium, which could influence readings when analyzing for these specific elements. BR-127NC is essentially the same as BR-127, but without the chromium – critical for some detector applications.

Health & Safety Note:

Handling solid beryllium material poses no special health risk. Like many industrial materials, beryllium-containing materials may pose a health risk if recommended safe handling practices are not followed. Inhalation of airborne beryllium may cause a serious lung disorder in susceptible individuals. The Occupational Safety and Health Administration (OSHA) has set mandatory limits on occupational respiratory exposures. Read and follow the guidance set forth in the Safety Data Sheet (SDS) before working with beryllium. For additional information on safe handling practices or technical data on beryllium, contact Materion Electrofusion.

ELECTROFUSION
44036 South Grimmer Boulevard
Fremont, CA 94538-6346
+1 510.623.1500
electrofusion@materion.com

MATERION CORPORATION
www.materion.com/electrofusion

Impermion is a trademark of Materion Brush Inc.
BR is a registered trademark of Cytec Engineered Materials

EQF 30-15 05/2016

X-ray Windows

DuraBeryllium® Windows in Conflat Flanges

Technical Note

DuraBeryllium Window in Conflat Flange

Moxtek® offers DuraBeryllium® windows mounted in vacuum fittings (CF flanges) with a proprietary high temperature metal seal and both DuraCoat® and DuraCoat Plus protective films. DuraBeryllium windows have high x-ray transmission, high temperature tolerance, and excellent corrosion resistance.

For details about DuraBeryllium windows, please refer to the DuraBeryllium Windows datasheet (WIN-DATA-1003) at www.moxtek.com.

Applications

- X-ray Fluorescence
- Synchrotron
- X-ray Diffraction

Features	Benefits
DuraCoat®	Corrosion resistance, hermetic seal
DuraCoat® Plus	Maximum corrosion resistance
Thin Beryllium	High transmission of low energy x-rays
Uniform thickness	Consistent transmission
Vacuum tight	No gas diffusion
Standard stainless steel Conflat design	Fits standard vacuum fittings
	Corrosion resistant metal flange
Metal bond seal	Hermetic seal
	High temperature exposure

Geometry and Sizes

The geometry of the window frame is shown in Figure 2 and in Table 1. The typical assembly of the Beryllium window is shown in Figure 1.

Figure 1 Typical Assembly of Beryllium Window

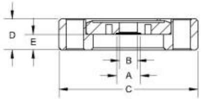


Figure 2 Conflat Flange Geometry

Table 1 Dimensions of Conflat Flange Options (Refer to Figure 2 above)

CF	Foil Thickness (µm)	Foil Diameter (mm) - A	Through Hole Diameter (mm) - B	CF Outer Diameter (mm) - C	CF Thickness (mm) - D	Window Height (mm) - E	Coating	Part ID
1-1/3" OD	8.0	9.2	7.0	33.8	7.2	0.5	DuraCoat Plus	DBM-08-9.2-CF1.3-P
	25.0	16.0	13.0	33.8	7.2	0.5	DuraCoat	DBM-25-16.0-CF1.3
2-1/8" OD	8.0	9.2	7.0	53.6	11.9	6.5	DuraCoat Plus	DBM-08-9.2-CF2.1-P
	25.0	16.0	13.0	53.6	11.9	6.5	DuraCoat	DBM-25-16.0-CF2.1

MOXTEK®

WIN-TECH-1001, Rev C
Subject to technical change without notice

Fermilab

Conclusion

- Vacuum windows are critical components of the accelerator complex
- The fragility and potential of harm from windows has historically been not recognized
- Safety has to have higher priority since the future experiments will involve higher beam intensities which may necessitate the use of beryllium as the foil material
- The robustness and design of vacuum windows impacts the experiments in crucial ways

Questions?

Thank you!