Accelerator Vacuum Windows: A Review of Past Research and a Strategy for the Development of a New Design for Improved Safety and Longevity for Particle Accelerators

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Agenda

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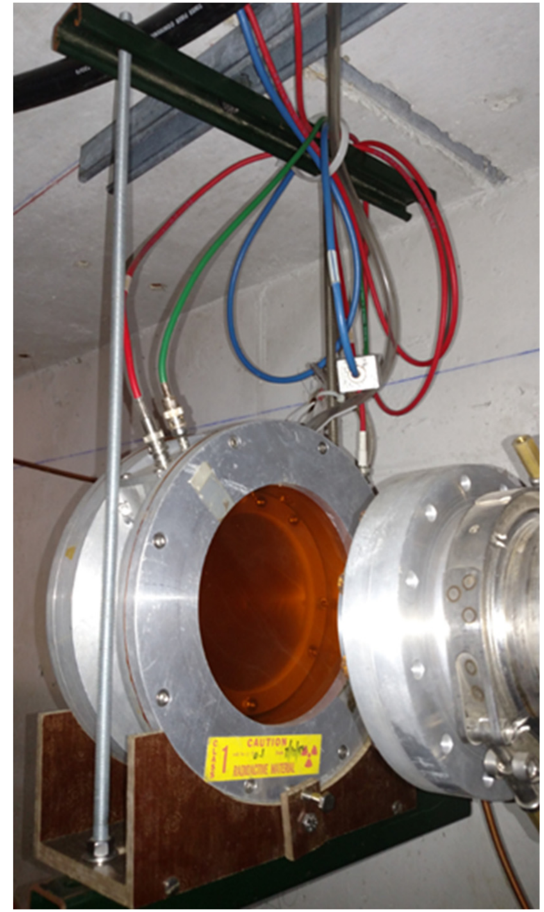
4. Fabrication and Operating Costs
5. Geometry
6. Failure Root Cause Analysis (FRCA)
7. Conclusion

Introduction

- Vacuum windows: thin separation between a volume under vacuum and a volume at atmospheric pressure or vacuum and through which primary or secondary beam passes.
- Vacuum window is any thin material that isolates volumes of beam tube.
- There are approximately 83 vacuum windows in operation at Fermilab, 5 made of beryllium.
- Photo shows a Switchyard ion chamber and an upstream vacuum window



Cost Benefit Analysis of a Newly Designed Vacuum Window

- A critical aspect of material selection of vacuum windows is examining the costs and benefits of using different materials.
- The costs of fabricating a new design of a window is quite expensive, and is typically not fully appreciated, particularly in terms of the engineering time that is involved in the analysis.
- Based on a cost-benefit analysis of the two materials typically used at Fermi, the total cost of fabricating and maintaining a new beryllium vacuum window is almost $90K, in addition to toxicity concerns.
- Most of the cost is the engineering analysis time, about $36K, while about $20K is clean-up costs if a window fails.

Cost Benefit Analysis of a Newly Designed Beryllium vs. Titanium Window

Cost-Benefit Analysis of Beryllium vs. Titanium Vacuum Windows			
	Beryllium	Titanium	Notes
Design	$36,000	$36,000	200 hours (Be NuMI Target Window)
Drafting	$16,250	$16,250	100 hours
Fabrication	$2,826	$5,000	
Q/A & Inspection	$2,000	$300	
Cleaning	$500	$150	
Leak checking	$300	$150	
Storage/Handling Costs	$3,000	0	
HA, Safety Documention	$2,000	$500	
Installation Cost	$5,000	$5,000	
Operational Cost	$1,000	$1,000	
Failure/Clean-up Cost***	$19,500	$2,000	
Disposal/Storage Cost	$3,000	0	
Total	**$91,376.00**	**$66,350.00**	

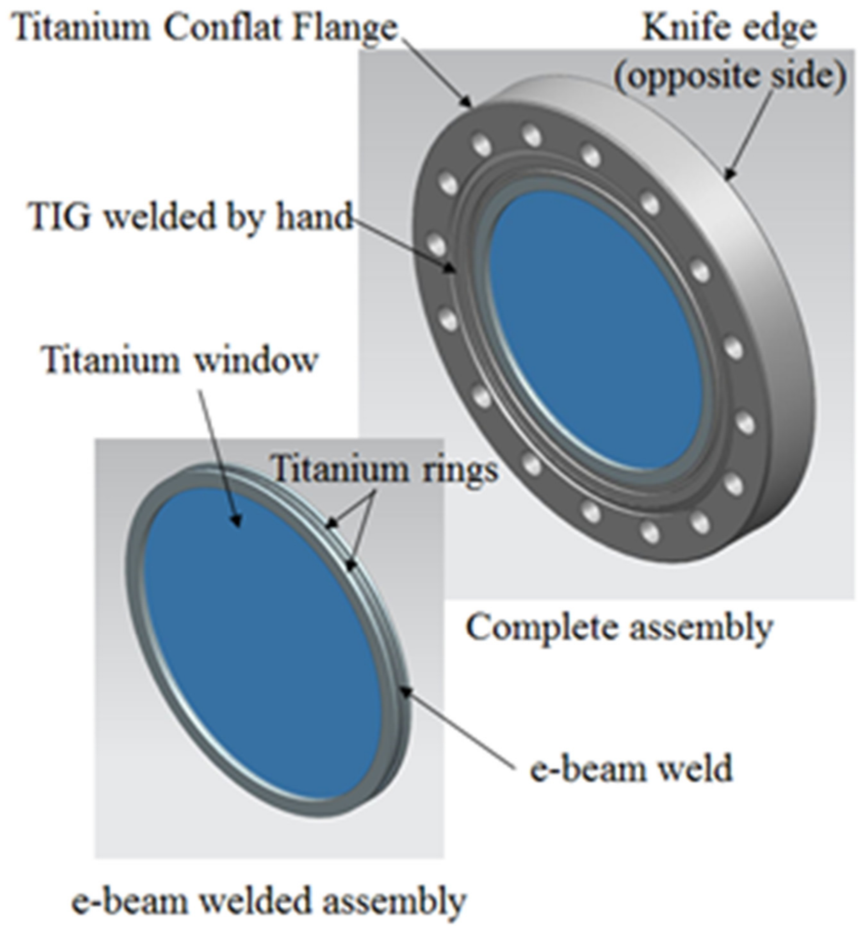
Design

- Fabricated by an electron-beam process which involves first sandwiching the foil between two Titanium weldments.

- Next, this weldment is TIG hand-welded into a custom Titanium Conflat flange.

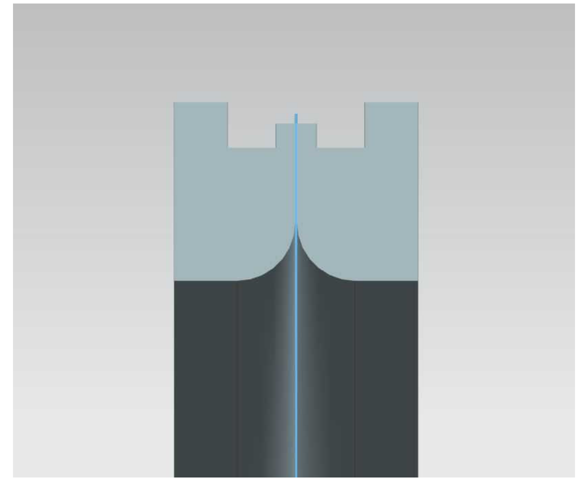
- This design is symmetrical, and the edges are smooth and have no sharp edges. This allows the flange to accept pressure from either side and is a much more robust design.

Electron-Beam Welded Window Assembly



Design of Joint is Critical

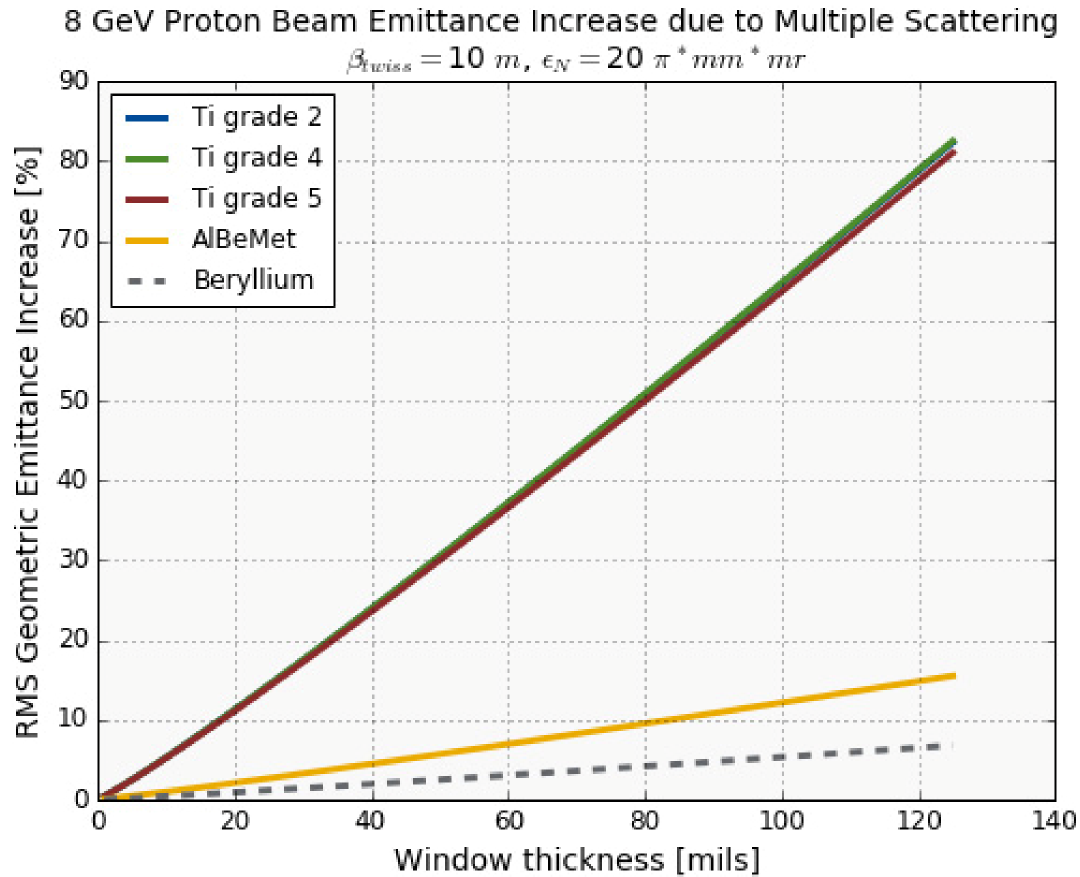
- The best-designed joints take into consideration that the load can come from either direction.
- Symmetrical joint design with no sharp edges is best.
- Furnace vacuum brazing or Electron-beam welding are typical fabrication techniques.
- Joint clearance on furnace braze joints needs to specified.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



Window Design: Beam Emittance

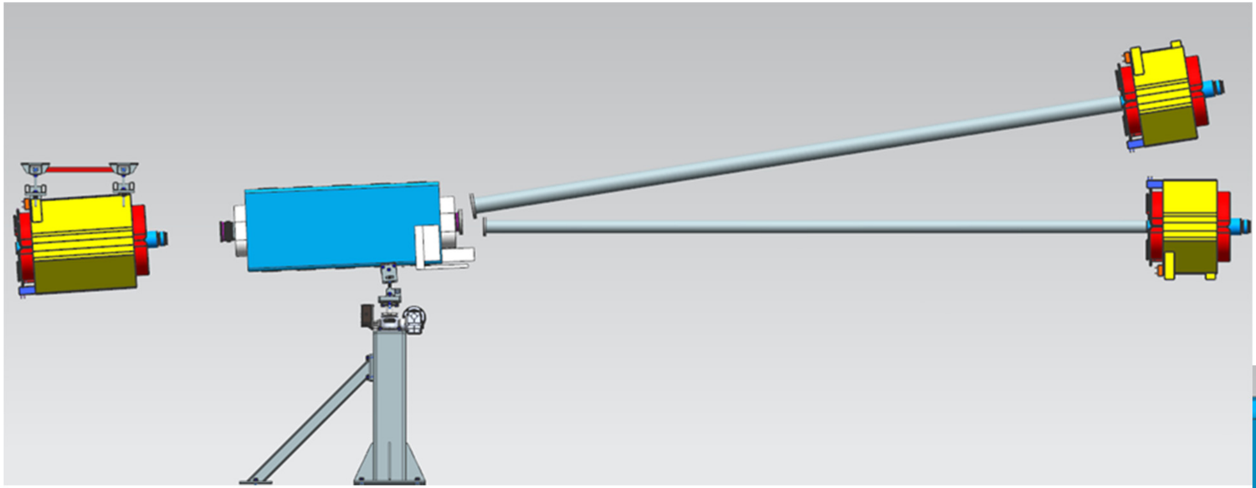
- Window thickness is a critical design consideration.
- It can be challenging to design a window that meets both mechanical and beam physics constraints.
- Beam emittance increases as a function of vacuum window thickness for different common materials.

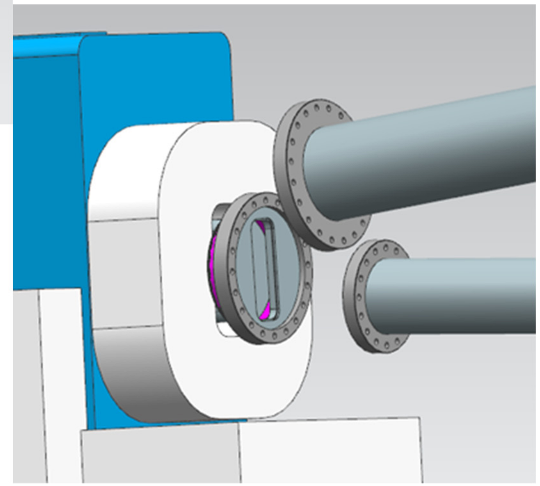
Window Design: Beam Emittance, cont.



Fermilab

Window Design: Geometry



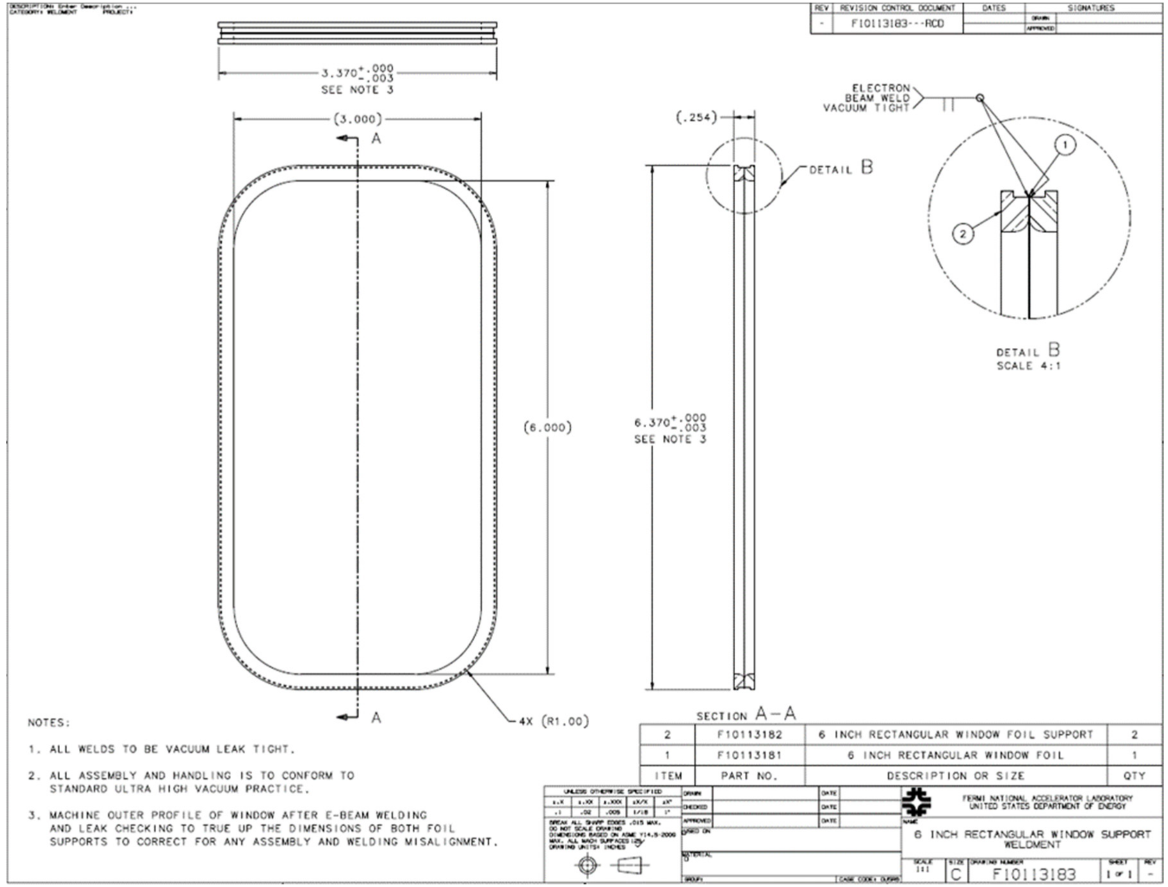


- One of these modes is for rapid change over between Mu2e and g-2 running.
- Having a window allows the V907 magnet to pivot without putting stress on components such as bellows.

Window Design: Geometry, cont.

- A Muon Campus Vacuum new design window consists of a 6-inch by 3-inch rectangular grade 5 Titanium (Ti-6Al-4V) foil that is .004” thick. This foil is placed between two support rings made of grade 2 titanium.
- These support rings have a .05” radius to relieve stress when the foil window flexes under vacuum.
- The next slide shows how the support rings and foil window attach.

Window Design: Geometry, cont.

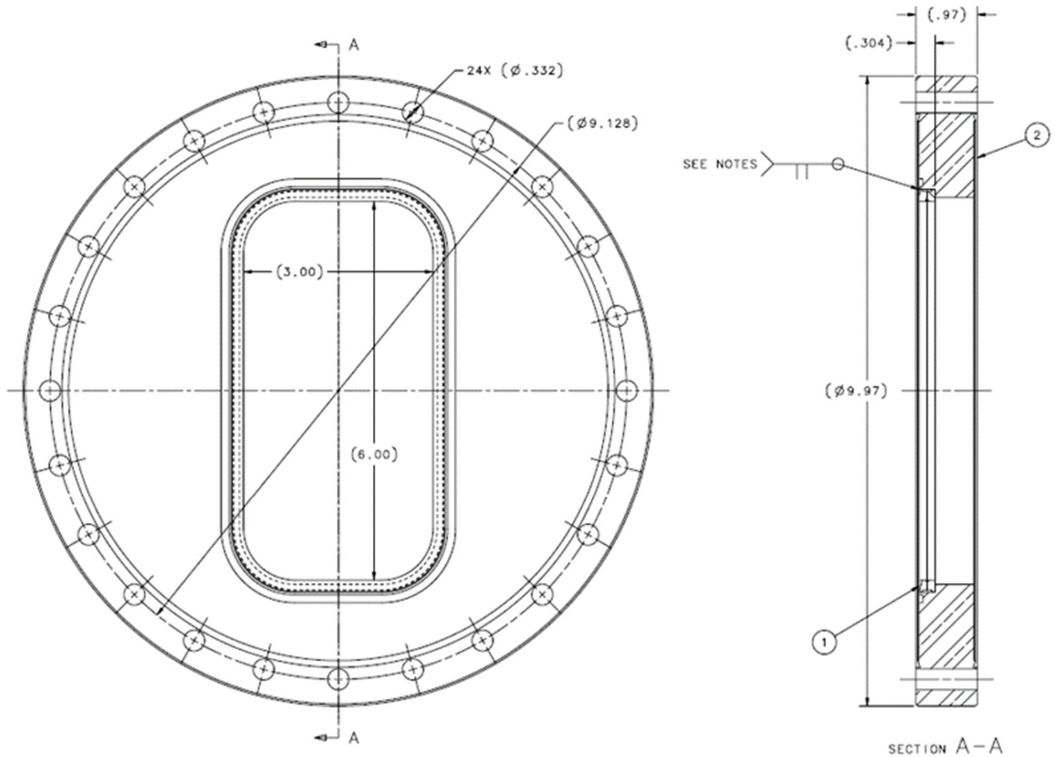


Window Design: Geometry, cont.

- The electron-beam welded assembly is then placed into an 8” diameter grade 2 titanium conflat flange that is prepared to receive the welded assembly and then welded into place.
- The next slide shows the finished welded assembly.

Window Design: Geometry, cont.

The support rings and titanium foil (item 1) is welded to the conflat flange (item 2).

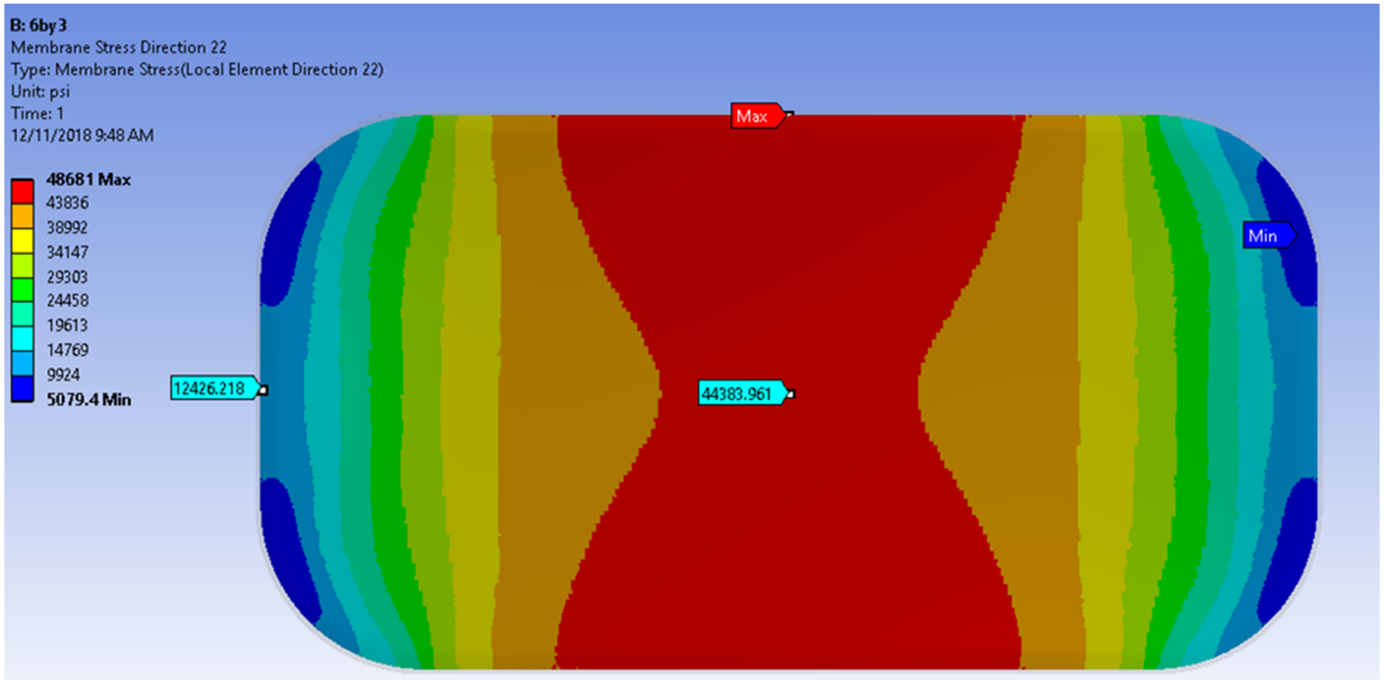


Geometry, cont.

- This type of design has never been done before.
- An FEA analysis and hand calculations were done on the rectangular window.
- The ANSYS conclusion agrees with the hand calculations. In ANSYS, the max stress of 48,681 psi is acting on the edge while the center has a stress of 44,384 psi which agrees with the hand calculations.
- The elevated edge stress is most likely due to the contact between the foil and the radius on the support ring.
- The next slide shows the membrane stress calculated with ANSYS.

Window Design: Geometry, cont.

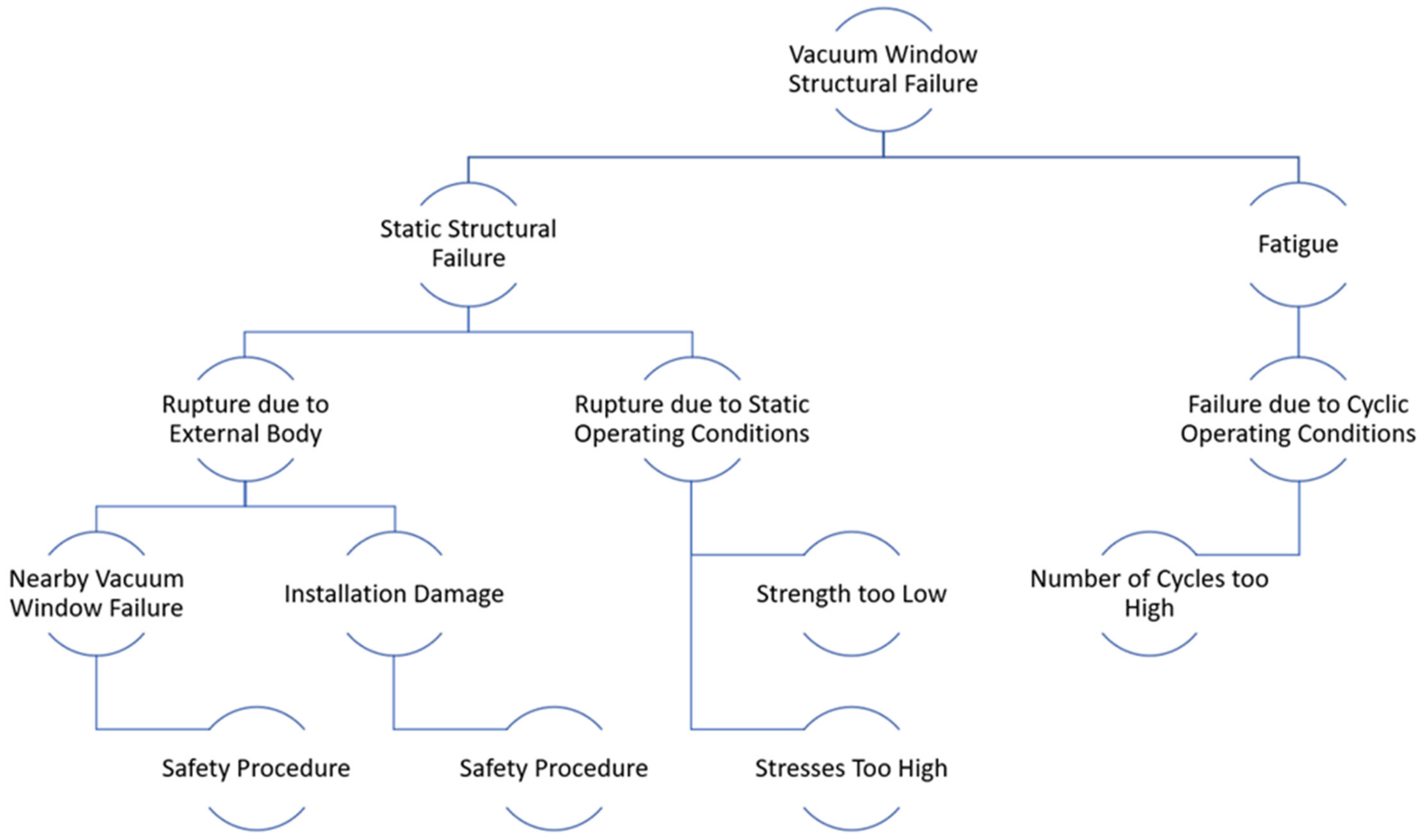
Ansys membrane stress results: the max stress of 48,681 psi is acting on the edge while the center has a stress of 44,384 psi



Failure Root Cause Analysis

- A failure root cause analysis (FRCA) is used to help minimize or mitigate risk of potentially harmful effects associated with a vacuum window failure.
- This FRCA is used as well as the Fermilab safety chapter, FESHM 5033.1, to ensure that we build a safe and reliable window and have considered all potential failure modes.
- One of the considerations for operating costs is clean-up costs. So mitigating failures is a very cost effective strategy.

Failure Root Cause Analysis



Failure Root Cause Analysis: Static Structural

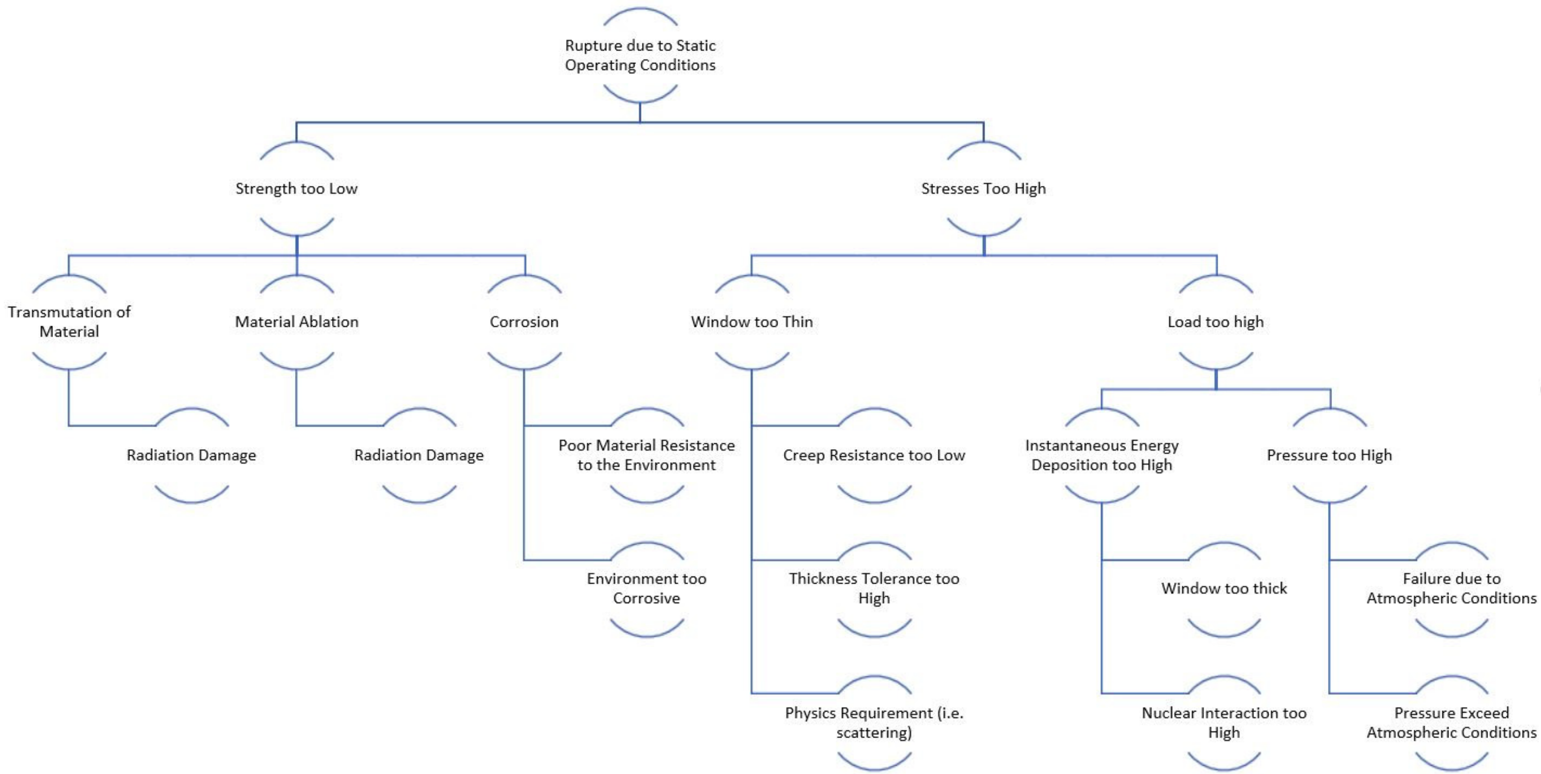
- The static structural failure occurs with no cyclic forces. These failures occur when there is accidental damage during installation. These can be mitigated by a safety procedure.

- The following figure show the continuation of the FRCA tree and shows a primary modes of failure: static structural operating conditions.

- Static loading can cause a rupture when the vacuum window strength is too low. This is possible when the material becomes radiation damaged and the base material changes.

- Additionally, the material can also sputter away in some cases as well as corrode due to the environment, which can cause a window failure.

Failure Root Cause Analysis: Static Structural



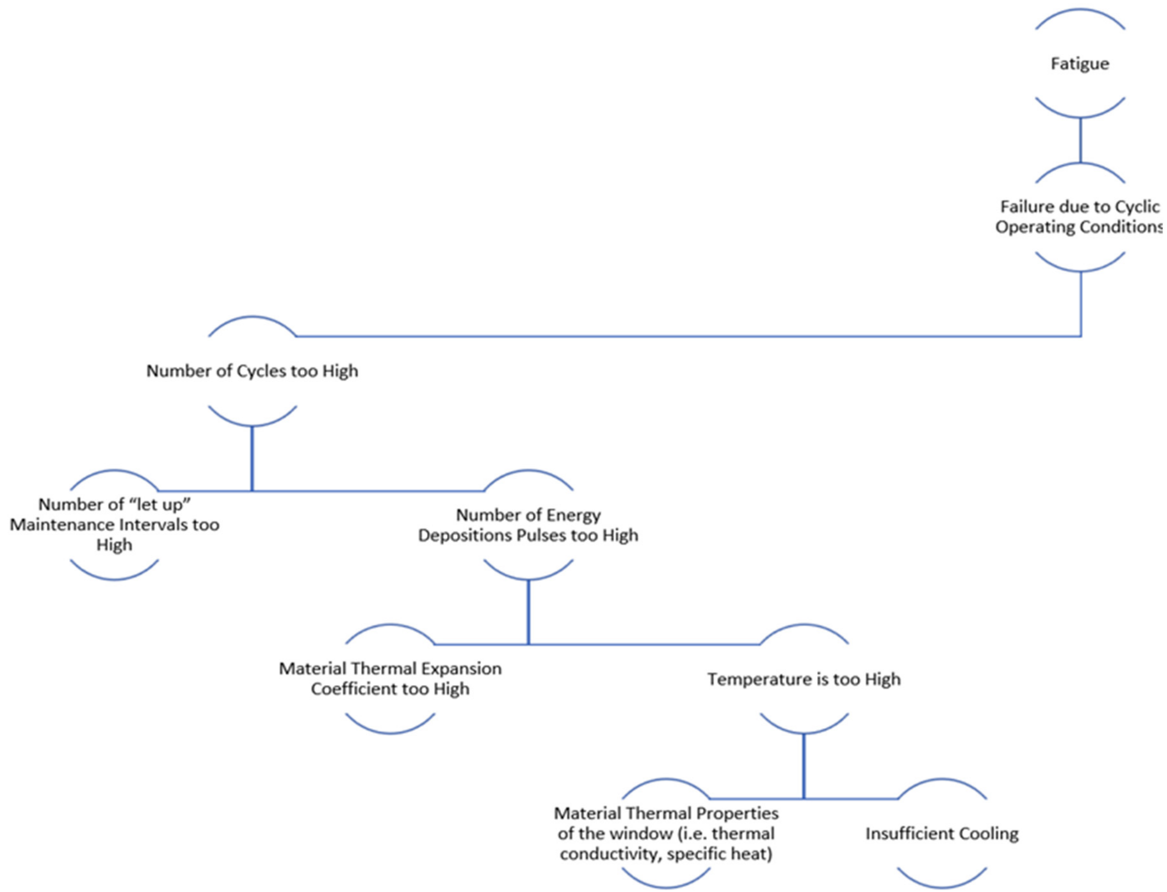
Failure Root Cause Analysis: Fatigue

- The next figure illustrates that fatigue can cause a window failure due to cyclic structural or thermal-structural conditions.

- When a window is “let-up” to atmosphere from vacuum, the stresses on the window tend to zero, but after so many “let-up” and “pump-down” cycles, a window can rupture and no longer hold vacuum.

- As beam passes through the window, it will deposit some of its energy into it. The heating and cooling cycle after each pulse of the beam also can weaken the material.

Failure Root Cause Analysis: Fatigue



Conclusion

- Safety has to continue to have high priority since the future experiments will involve higher beam intensities which may necessitate the more frequent need of beryllium as the foil material.
- We plan on testing new materials which are stronger and less expensive than the typical materials we are using for vacuum windows in the accelerators, particularly beryllium.
- When the feasibility of a new window design is demonstrated, further irradiation studies in hot cells, which is typically used for target materials, will be done.
- In addition, tests of the rectangular window design will be completed in the near future.

Questions?

Thank you!