Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science

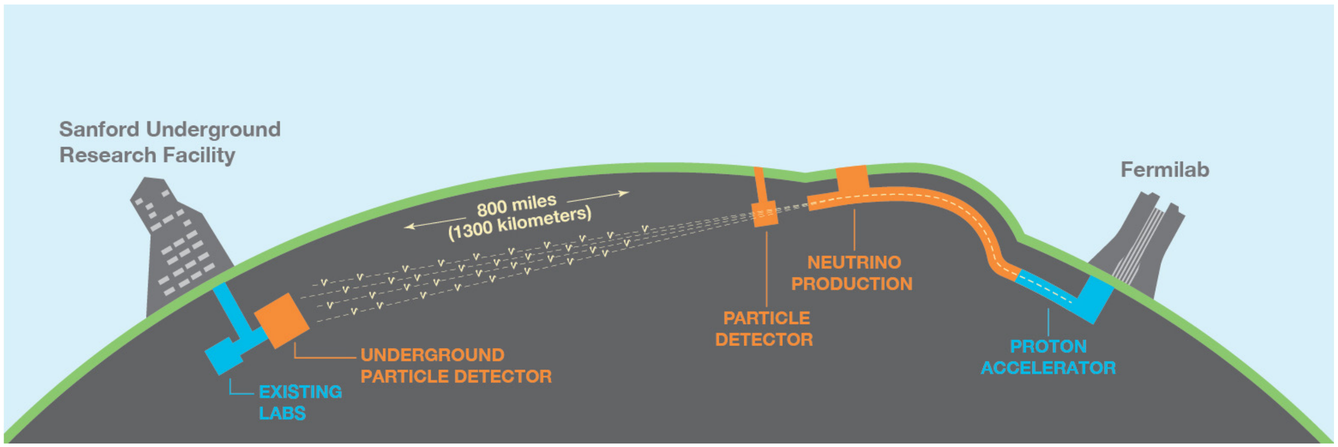
Decay Pipe Windows Final Design Review

Quinn Peterson
Decay Pipe Windows FDR
26 June 2024

Topics

- LBNF/DUNE Intro
  - Beamline and NSCF are currently preparing for baselining/early procurements (CD2/3)
- Decay Pipe Windows review
- Charge Questions
- Decay Window Overview
  - EDMS Requirements
- Interfaces
- Risks
- Schedule
- 01/25/24 Peer Review
- DSDP Window
  - Design
- USDP Window
  - Design
  - Cost
  - Installation
  - QA/QC

DUNE & LBNF

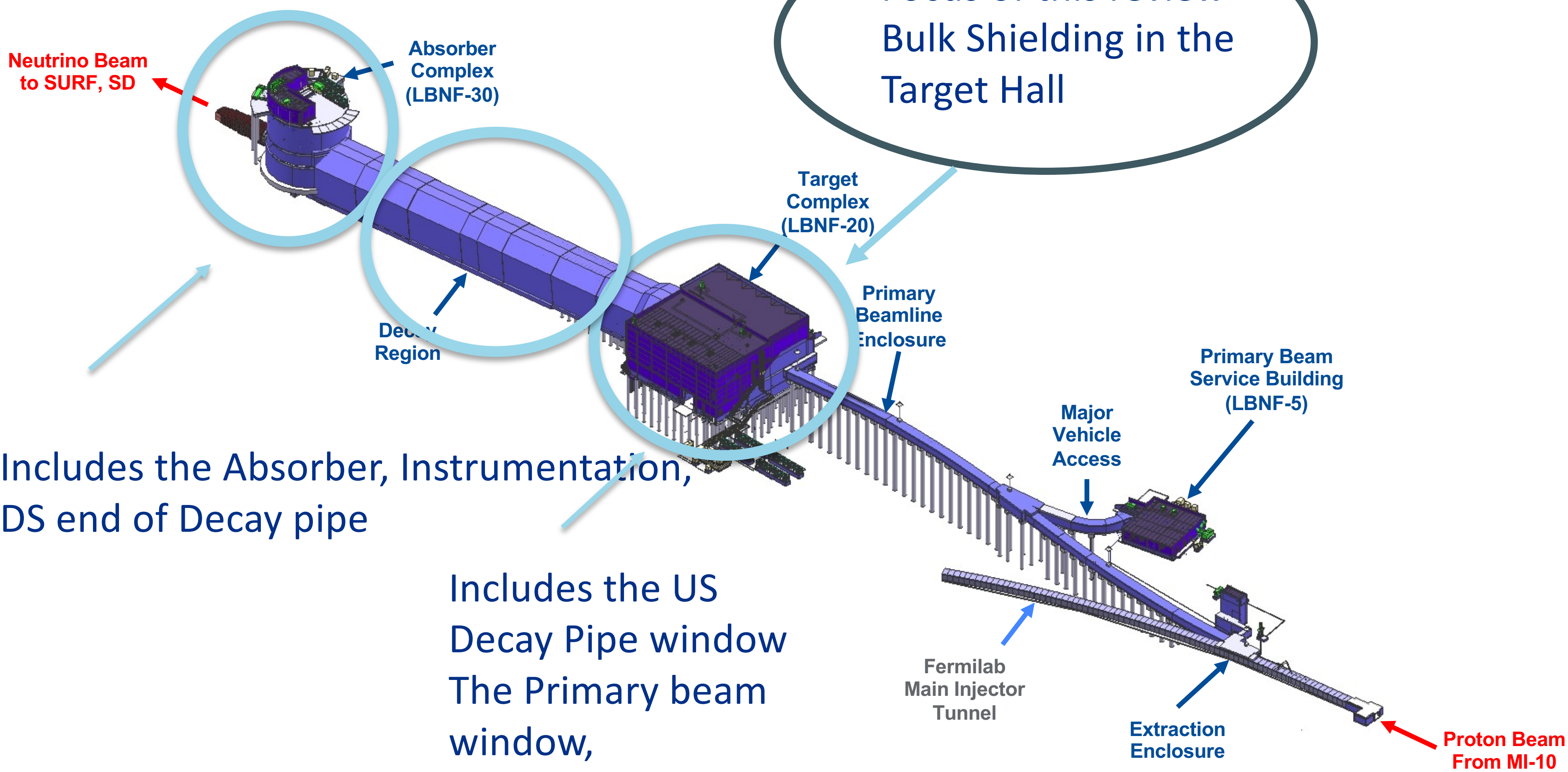


The Deep Underground Neutrino Experiment will be a world-leading experiment for neutrino science, potentially transforming our understanding of why the universe exists as it does.
The Long-Baseline Neutrino Facility is the infrastructure necessary to send a powerful beam of neutrinos 800 miles through the earth, and measure them deep underground at South Dakota's Sanford Underground Research Facility.
DUNE/LBNF project will be the first internationally conceived, constructed, and operated mega-science project hosted by the DOE in the U.S.

The beamline is designed to commission at 1.2MW and increase to 2.4MW

WBS 131.NSCFB.03.04 Scope

Focus of this review – Bulk Shielding in the Target Hall



Includes the Absorber, Instrumentation, DS end of Decay pipe

Includes the US Decay Pipe window
The Primary beam window,
Instrumentation

Decay Pipe Windows Final Design Review

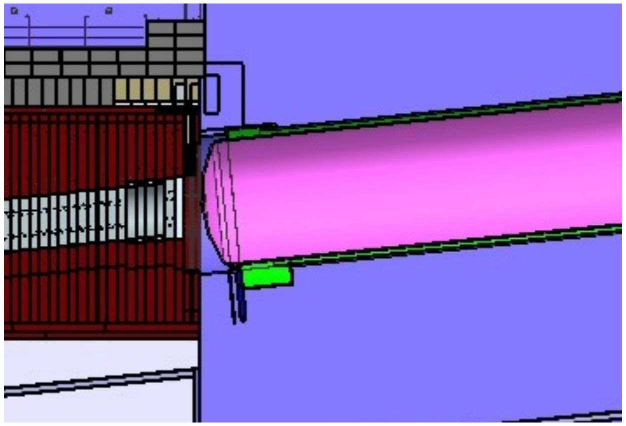
- Technical Peer Review Conducted January 25, 2024
  - Committee: Patrick Hurh, Kris Anderson, Kavin Ammigan
- The design of the Decay Pipe windows is ready for final design review
  - Technical Peer review recommendations have been addressed or are close to completion
  - Drawings are done
  - The design is sufficiently mature
- The Upstream Decay Pipe Window is being designed, procured, and fabricated and installed under the Beamline Scope.
- The Downstream Decay Pipe Window is being designed and installed by CF as part of the Decay Pipe System. Beamline Scope is to provide a thermal/structural analysis including beam energy deposition to be appended to the AECOM FESHM 5031.5 engineering note and will be included as part of the FESHM Peer Review.
- Note that the Upstream Decay Pipe Window and associated documentation refer to and rely in part on the design of a Remote Exchange Mechanism, however, this mechanism is outside of the scope of this review
- This review will help to confirm our design choices, cost and schedule

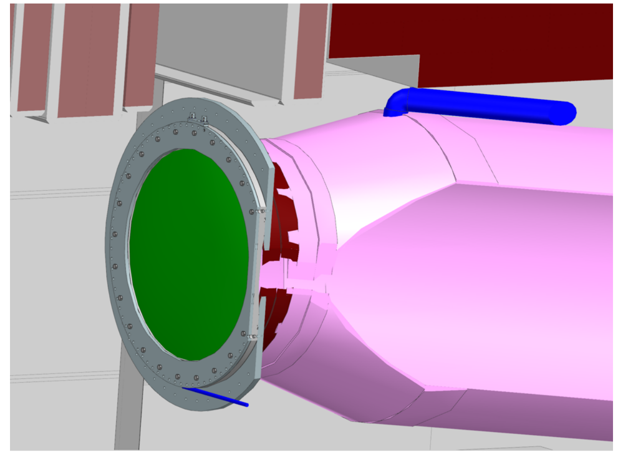
Charge #

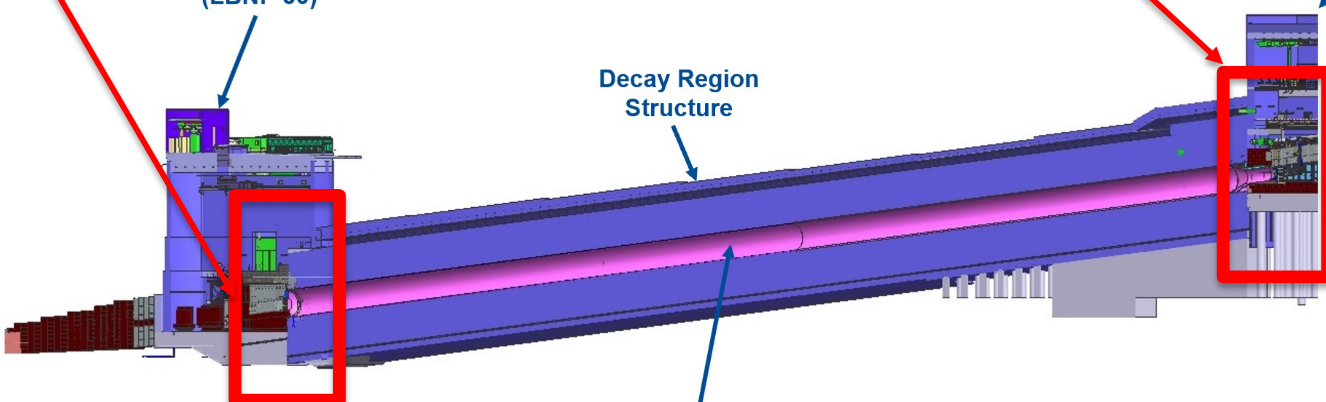
Charge Questions

1. Do the design choices satisfy the requirements?
2. Have all engineering analyses been performed and documented, and reviewed/peer reviewed and approved, where applicable? Does it meet FESHM standards?
   a. Are all 2D/3D mechanical model drawings complete and documented?
   b. Is there a centrally maintained, accessible to all, CAD assembly model with the appropriate level of detail needed for an integration model?
3. Have all lessons learned been incorporated into the final design?
4. Have the ESH issues been identified and analyzed appropriately?
5. Are installation, and testing plans in development?
   a. Have sufficient resources for installation and testing been identified?
6. Do project planning materials including interface documents, QA/QC plans, risk assessments, schedules, and cost estimates exist at a sufficient level of development for this stage of the design?
7. Have all recommendations from previous reviews been adequately addressed and approved by the relevant authority?
8. Has a peer review been done on the analysis?

Decay Windows Overview



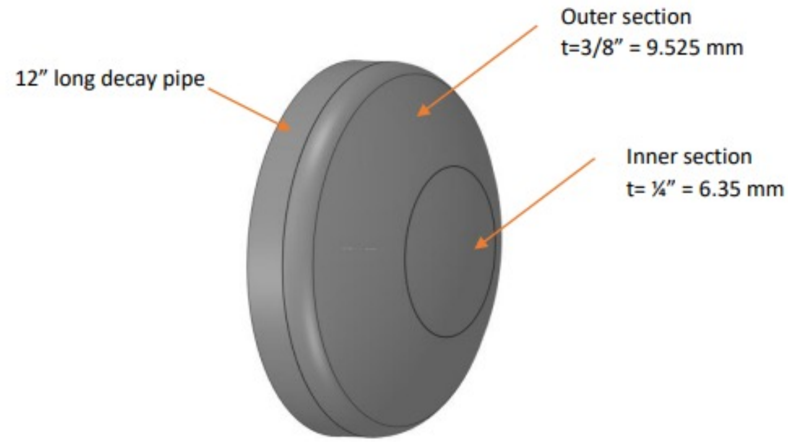


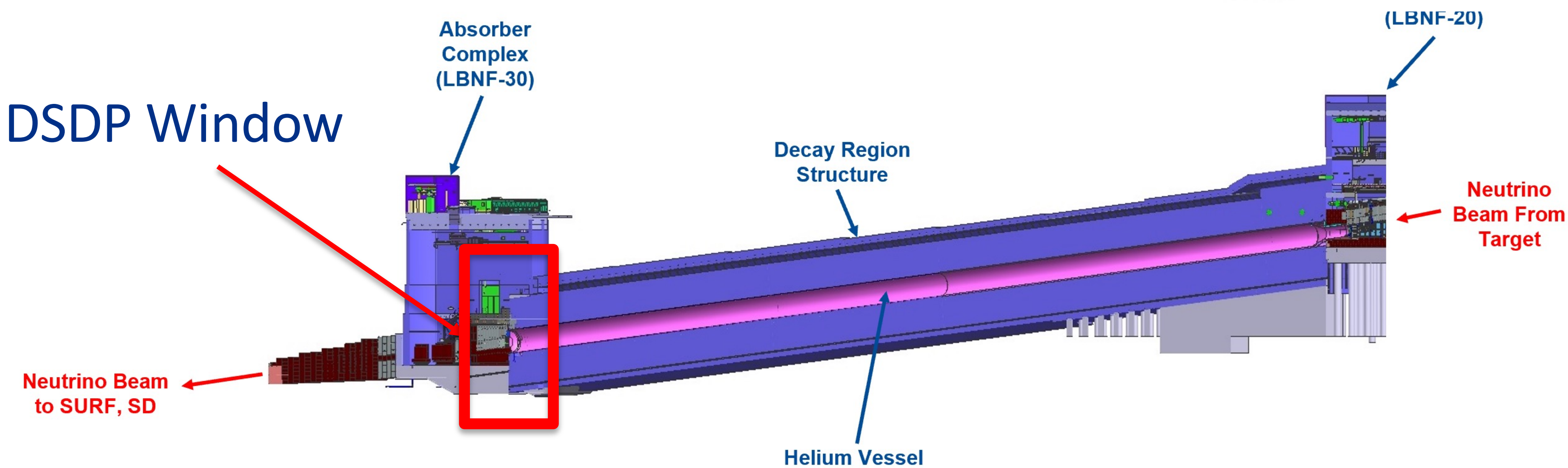


Comprises a Low Press Vessel Per FESHM 5031.5

DSDP Window Overview

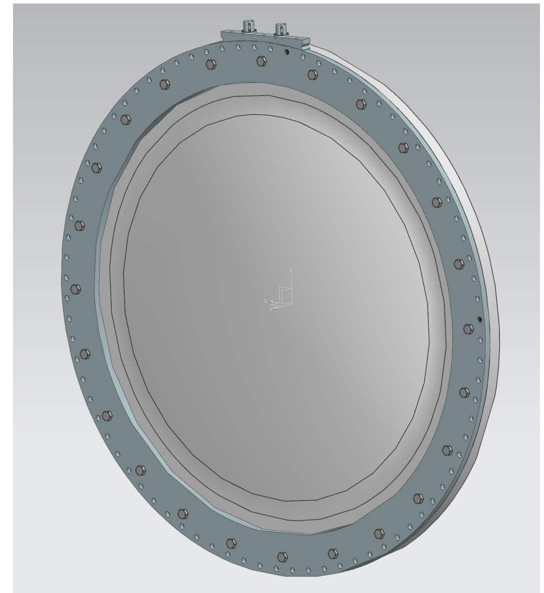
- As this “Window” design is a weldment on the downstream end of the Decay Pipe, this assembly is considered a part of the pressure vessel and is designed, installed and tested by AECOM.
- Beamline is responsible for providing design requirements and Thermal/Structural analysis to include beam loading on the window for design validation
- Designed for 2.4MW Operation as this cannot be upgraded

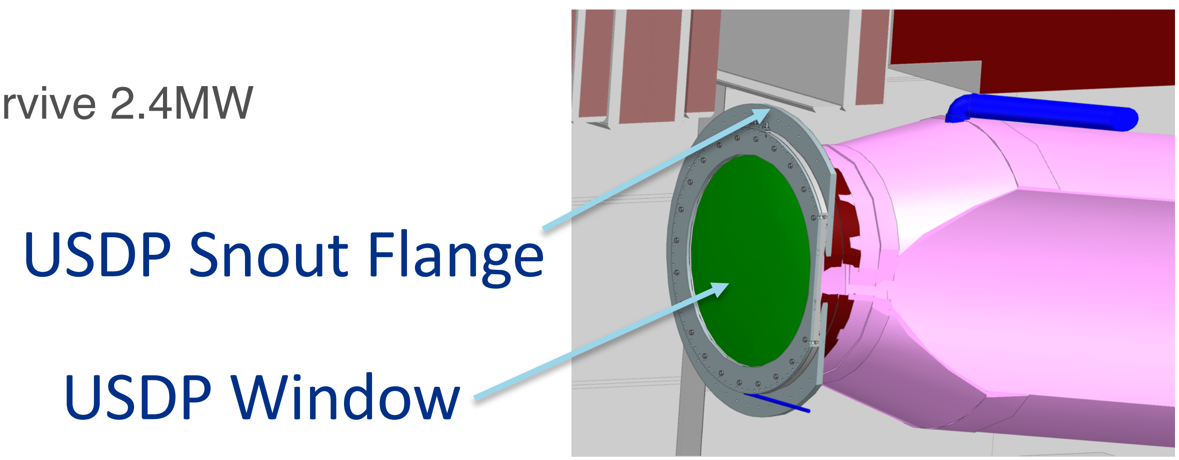




USDP Window Overview

- 1.8m Diameter Al-6061-T6 aluminum window provided by Beamline to be installed at the Upstream Decay Pipe Snout Flange.
- This is designed as a removable window separate from the Decay Pipe and a separate engineering note will be generated and attached to the AECOM note.
- The flange defines the line that separates the Beamline deliverable USDP Window from the CF provided Decay Pipe structure at the USDP Decay Pipe Snout
- Designed for 1.2MW but should survive 2.4MW operation





Decay Windows Overview

Requirements:

- USDP Window:
  - 1. Shall be replaceable consistent with safety practices
  - 2. Shall incorporate best practices to maximize lifetime
  - 3. Shall have a maximum leak rate of 200 cubic feet helium per year
  - 4. Shall be transparent to the beam as conventionally possible while meeting accepted engineering standards for pressure safety and facility lifetime requirements
  - ~~5. Shall minimize decay pipe helium loss when a window replacement is required~~
    - Requirement 5 falls under the scope of the Remote Exchange Mechanism and will be reviewed during its FDR
- DSDP Window:
  - 1. Shall be designed such that it will not require replacement
  - 2. Shall incorporate best practices to maximize lifetime and consider corrosion in addition to thermal and pressure
- Absorber:
  - The absorber shall sustain at least 2 successive accident beam pulses without damage to components or loss of functional ability
    - While this is not a Decay Windows requirement, the windows must be able to sustain the accident case as well
    - Accident case is defined as No-Target beam activation.

Charge 6

Decay Windows Beamline Interfaces

LBNF Beamline Interface Matrix

New WBS	L3's	Owner	L4 Sub Project Interface Doc	Magnets	Magnet Power Supplies	Primary Water Systems	Beam Instrumentation	Primary Vacuum	Lattice Optics & Beam loss calcs	Magnet Installation	Beam Windows	Targetry (& Baffle)	Horns	Horn Power Supplies	Decay Pipe	Absorber	TH Shield Pile	RAW Water Systems	Radiation Physics	Remote Handling	Mars Modeling	Controls	Interlocks	Alignment	Installation Coordination	Conventional Facilities	Main Injector	Neutrino Beam Instrumentation	Cable coordination	Stripline
131.NSCFB.03.02.02	Phil Schlabach	George Velev	Magnets		1	2		5	6	141														57					153	
131.NSCFB.03.02.03	Phil Schlabach	Ramfis Rivera-Colon	Magnet Power Supplies			4																37	50		69	85			154	
131.NSCFB.03.02.04	Phil Schlabach	Dave Hixson	Primary Water Systems							143	150			14				35				38			70	86	103		155	
131.NSCFB.03.02.05	Phil Schlabach	Nathan Eddy	Beam Instrumentation					8	9	113			152									39		58	71		104		156	
131.NSCFB.03.02.06	Phil Schlabach	Kevin Duel	Primary Vacuum						10		11								117			40		59	72	151	105		157	
131.NSCFB.03.02.07	Phil Schlabach	John Johnstone	Lattice Optics & Beam loss							115														60		88	106			
131.NSCFB.03.02.08	Phil Schlabach	Kevin Duel	Magnet Installation																					145	146	147	148			
131.NSCFB.03.04.04	Mandy Kiburg	Quinn Peterson	Beam Windows												171		20	21		30	122	41		61	73	89				
131.NSCFB.03.03.02	Keith Gollwitzer	Pat Hurh	Targetry (& Baffle)										17				[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	
131.NSCFB.03.03.03	Keith Gollwitzer	Julio Ortega	Horns											18			24	25		32	124	43		63	75	149			159	175
131.NSCFB.03.03.04	Keith Gollwitzer	Chris Jensen	Horn Power Supplies																			44	53		76	90			160	173
131.NSCFB.03.04.02	Mandy Kiburg	Quinn Peterson	Decay Pipe													26			118		125	45		64		91			161	
131.NSCFB.03.04.03	Mandy Kiburg	Abhishek Deshpande	Absorber															28	119	33	126	46		65	77	92			162	
131.NSCFB.03.03.05	Keith Gollwitzer	Matt Slabaugh	TH Shield Pile															29	120	34	127	47		66	78	93		172	163	174
131.NSCFB.03.03.06	Keith Gollwitzer	Abhishek Deshpande	RAW Water Systems																121	35		48	54		79	94			164	
131.NSCFB.03.01.01	Jonathon Lewis	Kamran Vaziri	Radiation Physics																		129					133				
131.NSCFB.03.03.07	Keith Gollwitzer	Vladimir Sidorov	Remote Handling																		130	49	55	67	80	95		180	165	
131.NSCFB.03.01.01	Jonathon Lewis	Nikolai MokhoV	MARS Modeling																				132					136		
131.NSCFB.03.05.02	Rich Andrews	Mark Austin	Controls																				56		81	96	107	137	166	
131.NSCFB.03.05.03	Rich Andrews	Adam Olson	Interlocks																						82	97	108		167	
131.NSCFB.03.05.04	Rich Andrews	Virgil Bocean	Alignment																						83	98	109	138		179
131.NSCFB.03.05.05	Rich Andrews	Cons Gattuso	Installation Coordination																							99	110	139	168	177
	Rich Andrews	Kennedy Hartsfield	Conventional Facilities, Near																								111	140		176
	Rich Andrews	Dave Capista	Main Injector																										169	
131.NSCFB.03.04.05	Mandy Kiburg	Zarko Pavlovic/Jon Paley	Neutrino Beam Instrumentat																										170	
	Rich Andrews	Cons Gattuso	Cable Coordination																											
	Keith Gollwitzer	Giuseppe Gallo	Stripline																											

Beam Windows Interfaces: ICD's 20, 21, 30, 41, 61, 73, 122, 171

Charge 6

Decay Windows Interfaces

Beamline Interfaces:

- 20: BW to TH Shield Pile
- 21: BW to RAW Water System
- 30: BW to Remote Handling
- 41: BW to Controls
- 61: BW to Alignment
- 73: BW To Installation Coordination
- 122: BW to MARS Modeling
- 171: BW to Decay Pipe

All interfaces checked and approved by system owners

CF Interface:

- NSCF to Decay Pipe
  - Controlled in separate document than Beamline Interfaces. (Located docdb-31052)
  - Signed off by NSCF and Beamline

Decay Windows Risks

Charge 4, 6

- Engineering Risk Assessment
- Risk Register
  - Manufacturing/Procurement Issues
    - Contingency: 3mm thick USDP Window

Fermilab **Engineering Risk Assessment**

Project: LBNF Upstream Decay Pipe Window
Lead Engineer: Quinn Peterson
Reviewed By: Salman Tariq
Date: June 21, 2024

	Chapter	Engineering Risk Element								High Risk	Subtotal	Assessment
		A	B	C	D	E	F	G	H			
1	Requirements and Specifications	2	3				2		2	≥ 12	9	Standard Risk
3	Requirements and Specification Review	2	3		2	3	2		2	≥ 18	14	Standard Risk
4	System Design	2	3	3		3	2	3	2	≥ 21	18	Standard Risk
5	Engineering Design Review	2	3	3		3	2	3	2	≥ 21	18	Standard Risk
6	Procurement and Implementation		3		2	3	2	3	2	≥ 18	15	Standard Risk
7	Testing and Validation	2				3	2	3	2	≥ 15	12	Standard Risk
8	Release to Operations						2			≥ 4	2	Standard Risk
9	Final Documentation		3				2			≥ 7	5	Standard Risk

Project Risk Element								High Risk	Subtotal	Assessment
I	J	K	L	M	N	O	P			
2	3	2	2	2	4	1	2	≥ 25	18	Standard Risk

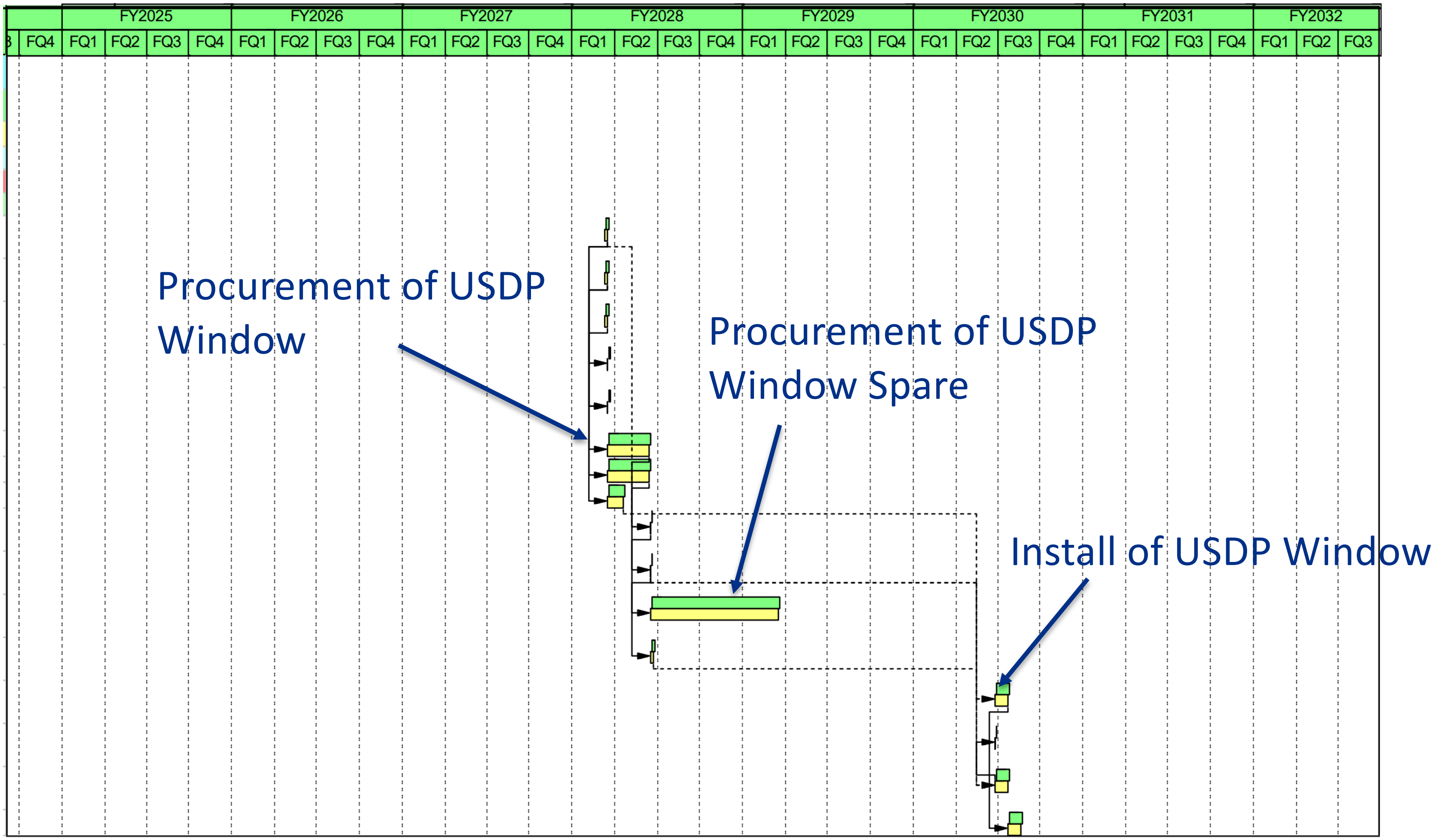
Engineering Risk Elements	
A	Technology
B	Environmental Impact
C	Vendor Issues
D	Resource Availability
E	Quality Requirements
F	Safety
G	Manufacturing Complexity
H	Transportation and Rigging Complexity

Project Risk Elements	
I	Schedule
J	Interfaces
K	Experience / Capability
L	Regulatory Requirements
M	Project Funding
N	Project Reporting Requirements
O	Public Impact
P	Project Cost

Risk Type	RI-ID	Title	Probability	Cost Impact	Schedule Impact	Risk Rank	Risk Status	Owner
Threat		BL - Risk: USDP Window 1.5mm Thick One-Piece D...	20 %	30 -- 50 k$	3 -- 6 months	1 (Low)	Proposed	Quinn R. Peterson

Schedule

Charge 6



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January Technical Peer Review Recommendations

Charge 8

Rec. #

- **Technical Peer Review 01/25/24**
  - Reviewers: Patrick Hurh, Kris Anderson, Kavin Ammigan

- Downstream Decay Pipe Window
  - 1. Evaluate and address comments on window materials and weld requirements with CF
- Upstream Decay Pipe Window
  - 2. Re-design the USDP as a one-piece machined window and flange
  - 3. repeat analysis with one-piece design geometry and apply updated parameters
  - 4. Perform in-depth bolted joint engineering design/analysis
    - Account for differential thermal expansion
    - Evaluate impact of clamping to a non-flat snout flange surface
  - 5. Consider using the flange seal leak check mock-up to test impact thermal cucling of the snout flange on the seal quality
  - 6. Consider adding a permanent water-cooling line on the snout flange to keep USDPW seal joint/flanges a more uniform and lower temperature

Charge 8

Rec. #

January Technical Peer Review Recommendations

Technical Review	**Beam Windows**	**LBNF Decay Pipe Beam Window Analyses Peer Review**	**2024-01-25**	1. Evaluate and address all comments above with CF.	1. Accepted		Accepted - Work In Progress
Technical Review	Beam Windows	LBNF Decay Pipe Beam Window Analyses Peer Review	2024-01-25	2. Re-design the USDPW as a one-piece machined window and foange with a tapered wall thickness to avoid stress concentrations and ease of fabrication.	2. Accepted	TC: F10118812	Accepted - Addressed/Closed
Technical Review	Beam Windows	LBNF Decay Pipe Beam Window Analyses Peer Review	2024-01-25	3. Repeat analysis with one-piece design geometry and apply relevant comments C4 through C7.	3. Accepted		Accepted - Work In Progress
Technical Review	Beam Windows	LBNF Decay Pipe Beam Window Analyses Peer Review	2024-01-25	4. Perform a more in-depth bolted joint engineering desing/analysis to account for differential thermal expansion and evaluate impact of clamping to a non flat flange.	4. Accepted	Docdb 31141	Accepted - Work In Progress
Technical Review	Beam Windows	LBNF Decay Pipe Beam Window Analyses Peer Review	2024-01-25	5. Consider using the flange seal leak check mock-up to test impact of the thermal cycling of the snout flange on the seal quality.	5. Accepted	Docdb 31135	Accepted - Work In Progress
Technical Review	Beam Windows	LBNF Decay Pipe Beam Window Analyses Peer Review	2024-01-25	6. Consider adding a permanent water cooling line to the snout flange to keep USDPW seal joint/flanges a more uniform and lower temperature.	6. Accepted	Docdb 31097	Accepted - Work In Progress
Technical Review	Beam Windows	LBNF Decay Pipe Beam Window Analyses Peer Review	2024-01-25	7. Specify the requirements for the US Decay Pipe window flange flatness ad bolt hole clocking tolerance, including an inspection deliverable document by the CF contractor	7. Accepted		Accepted - Work In Progress

1. BCR being processed. Once complete, recommendation is closed.
2. Design finalized and available on TC
3. Ang Lee's analysis is complete. A writeup once he returns from vacation will close this recommendation
4. Bolted analysis conducted and requires peer review. Successful peer review will close this recommendation
5. Thermal cycling added to pressure test procedure. Completion of the test and documentation of results will close recommendation
6. Consideration has been made and a discussion on the impact documented. Review and approval by Beamline will close this recommendation
7. Specification drawing being created with flatness and bolt hole clocking tolerance. Release and delivery to CF will close this recommendation

Downstream Decay Pipe Window

DSDP Window Design

Charge 2, 7, 8

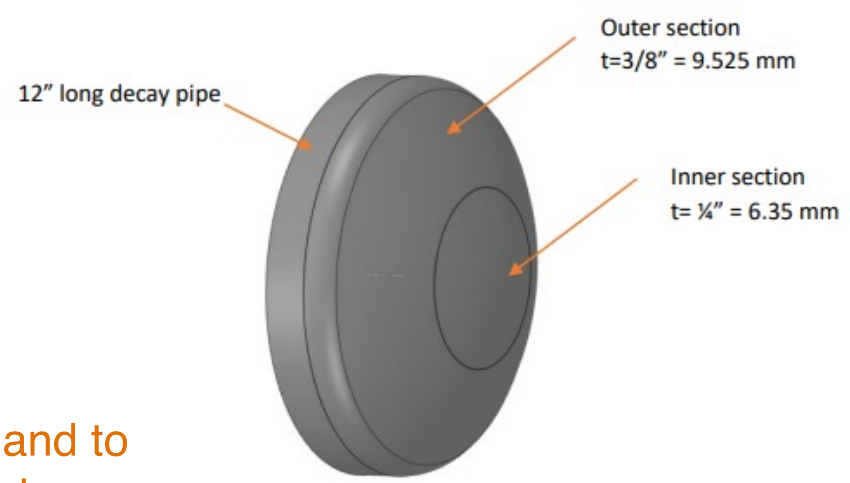
Rec. 1

- Specification Drawings located in Docdb-31052

- Material: S304L Stainless Steel
  - BCR Changing to S316L
- Thickness: Varies among sections
- Diameter Decay Pipe Connection: 4019.53 mm (13' – 2.25")
- Outer Section Diameter: 2743.2 mm (9')
- Inner Section Diameter: 1828.8 mm (6')

- Design Standards:
  - FESHM 5031.5
  - ASME BVPC, Section VIII, Div. 1 & 2
  - ASME XI

- BCR being conducted to use weld code NAS1514 and to specify weld passivation to increase corrosion resistance



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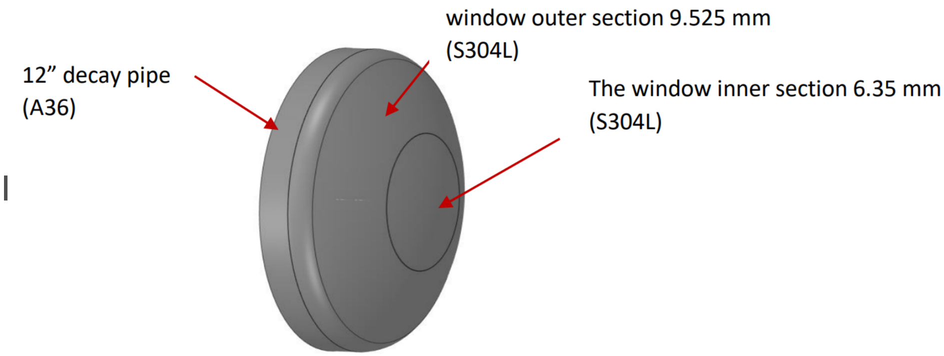
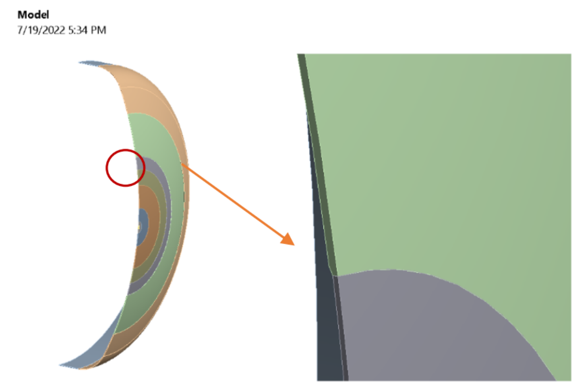
DSDP Window Analysis

Charge 2, 7, 8

- Overview
  - Design requirement to have window sustain accident case defined
  - Accident case investigated at 2 and 5 accident pulses
    - 2 pulses is design requirement, 5 is investigated for insight into how close to failure and accident case will bring the window
  - Analysis located at docdb-26309



- Model and Boundary Conditions:
  - Solid Model located in LBNF-doc-24999
  - Energy deposition provided by Igor Rakhno located in LBNF-doc-23236
  - Convective film coefficient hf=3 watt/m^2*K
    - Conservative natural convection
  - Fixed Temperature of 52C is placed at 12in Decay Pipe end based on AECOM analysis
  - Off axis (72 cm) accident case



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DSDP Windo Analysis

Charge 1, 2, 7, 8

- Thermal Results:
  - On Axis Tmax after 2 and 5 accident pulses:
    - Tmax 2 pulses: 155 C (311 F)
    - Tmax 5 pulses: 214 C (417.2 F)
    - Tmax change due to pulses: ~23 C/pulse (73.4 F)
  - Off Axis (72 cm) Tmax after 2 and 5 accident pulses:
    - Tmax 2 pulses: 158 C (316.4 F)
    - Tmax 5 pulses: 198 C (388.4 F)

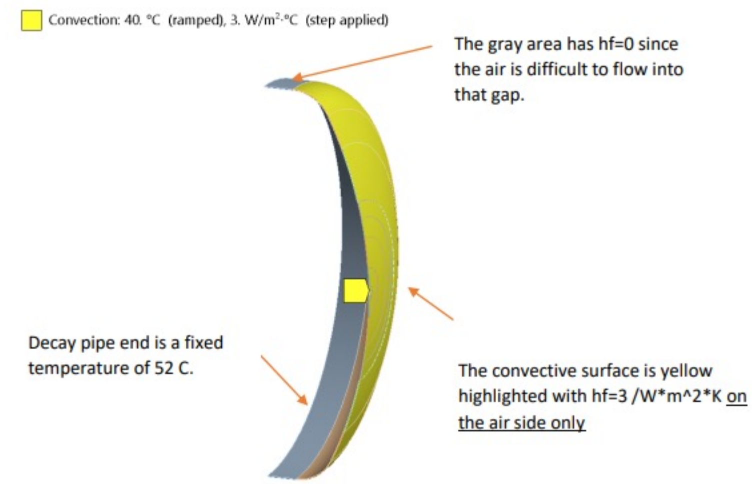
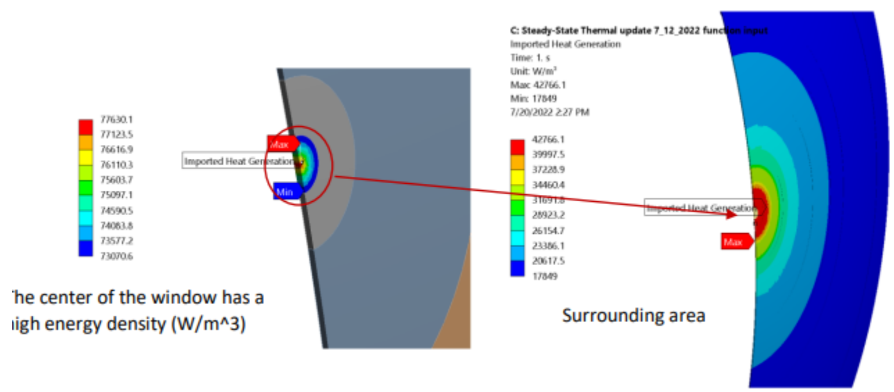


Table 1 Summary of thermal Result for the maximum temperature Tmax (C)

	Steady state Normal Operation	After 2 pulses _ On axis accident case	After 5 pulses _ On axis accident case	After 2 pulses _ Off axis accident case (720 mm)	After 5 pulses _ Off axis accident case (720 mm)
Tmax (C)	**107 C**	**155 C**	214 C	**137 C**	198 C
	The widow is cool initially (22 C everywhere)	**73.4 C**	135.2 C	**72.3 C**	135.3 C

Note:

1) For the accident case (transient solution) on 2nd row above table, the initial condition (t=0) is the normal OP condition.
2) For the accident case(transient) on 3rd row above table, the initial condition at t=0 is the 22 C everywhere.
3) The chance for 5 accident pulses occurring is very remote. Therefore, it is included here mainly for the purpose of reference only.



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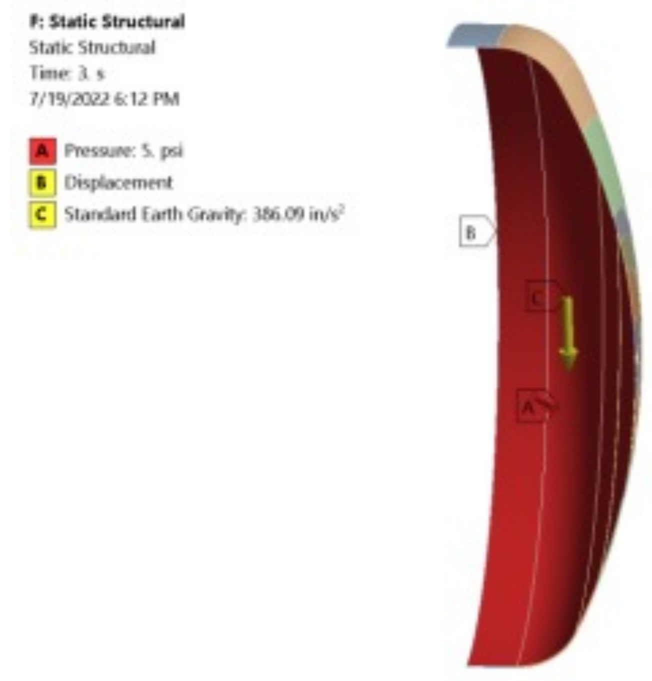
Decay Pipe Downstream Window Analysis Under 2.4 MW

Charge 2, 7, 8

- Structural Results:
  - On Axis:
    - 2 pulses: 13.5 ksi
    - 5 pulses: 28.2 ksi
  - Off Axis:
    - 2 pulses: 10.1 ksi
    - 5 pulses: 25.2 ksi
  - Per ASME VIII, DIV 2, part 5, allowable is 49.5 ksi
  - Stress around weld joint area is ~2.2 ksi regardless of normal or accident cases
  - Even after severe accident cases, the window remains functional



- Analysis approved at Technical Peer Review
- Analysis to be uploaded through TC and attached to AECOM FESHM 5031.5 note.
  - FESHM Note located docdb-23864

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Upstream Decay Pipe Window

USDP Window Design Overview

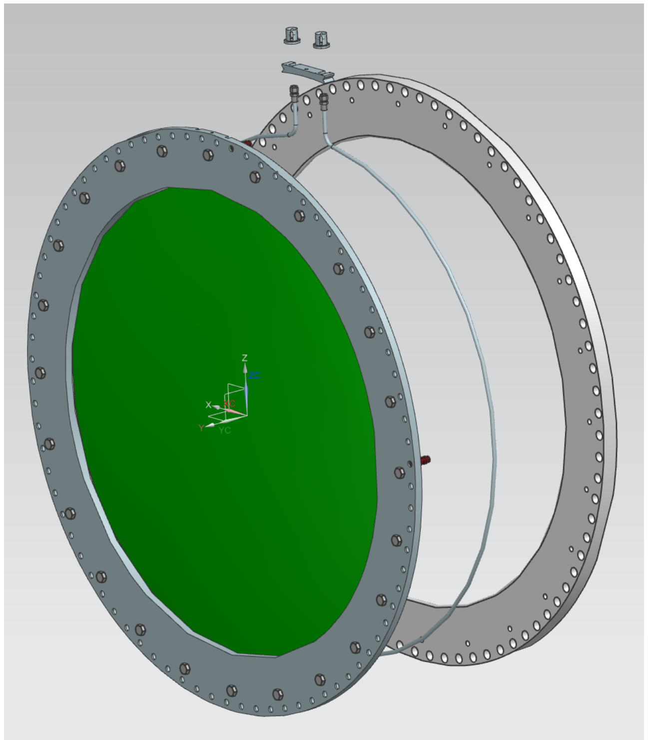
Charge 1, 2, 8

- Topics:
  - Dome Geometry
  - Capture Bolt System
  - Helicoflex Seal
  - Cooling Loop
  - Thermal/Structural Analysis
  - Bolt Joint Analysis

- Model controlled in TC: F10118812
  - Drawings Complete and compiled in docdb 31052

- Technical Peer Review conducted 01/25/24

- Design Standards:
  - Fermilab Engineering Manual
  - FESHM 5031.5, Low Pressure Vessel
  - ASME BVPC, Section VIII, Div. 1 & 2
  - ASME PCC-1, Guidelines for Bolted Flange Joint Assembly
  - MIL-HDBK-5, Metallic Materials and Elements for Aerospace Vehicle Structures

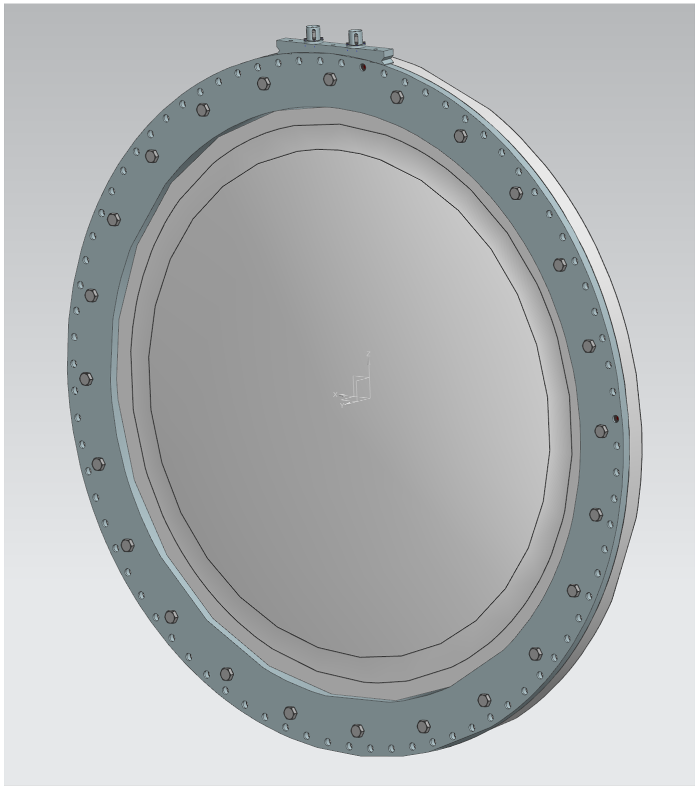


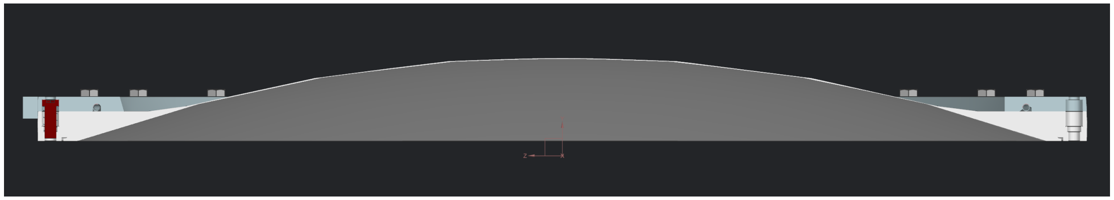
USDP Window Design Overview

Charge 1, 2, 7

Rec. 2

- Total Internal pressure against window.
  - MAWP = 5psi
    - Specified by AECOM in their engineering calculations
  - Interface with TH-Shield pile stating that internal pressure must be at or greater than TH Nitrogen
- Domed window is one-piece machined window
- Aluminum Window Diameter:
  - 1.5 m (~4.9 ft)
- Aluminum Window Thickness:
  - 1.5 mm (~0.06 in)
  - Thickness accepted and published in TDR as acceptable for neutrino yield
    - TDR located
- Outer Flange Diameter:
  - 1.8 m (~5.9 ft)





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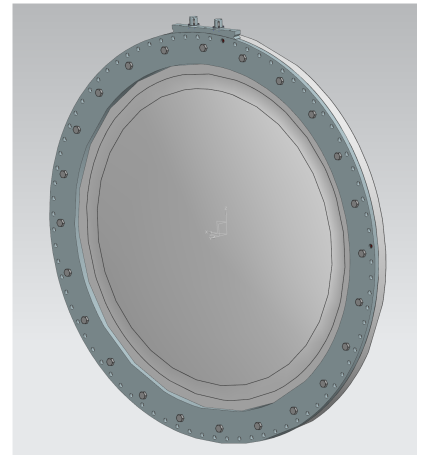
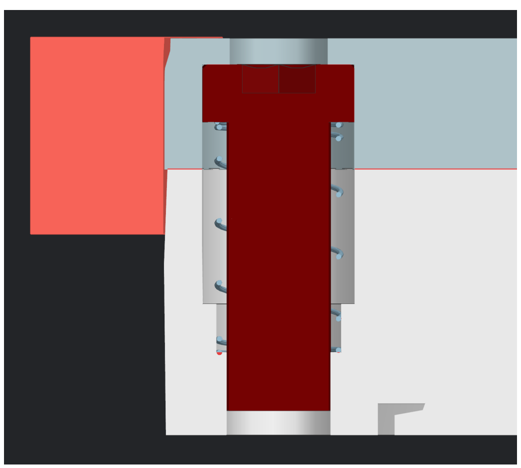
USDP Window Design Overview

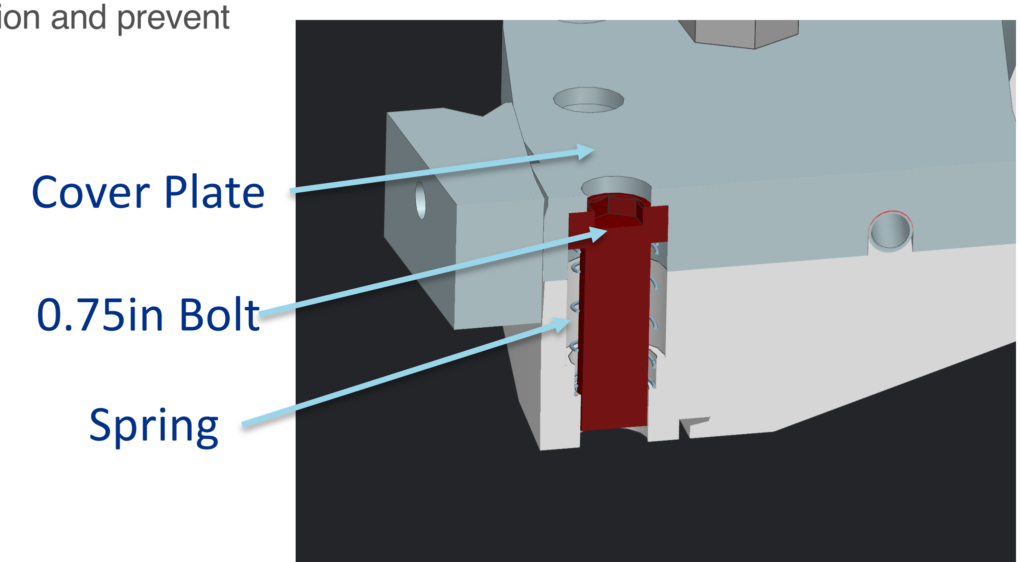
Charge 1, 2, 3



- Capture Bolts:
  - Design based on Mu2e target window capture bolts
  - Spring Loaded and held in place by cover plate
  - Spring compresses into pocket. Does not interfere joint compression
  - Design allows for bolts to be captured during a changeout procedure to assist with removable design

  - Bolt Size: ¾-16 in
  - Material: Grade 5 Titanium
    - Corrosion Resistant
    - Tungsten Disulfide coating to reduce friction and prevent galling

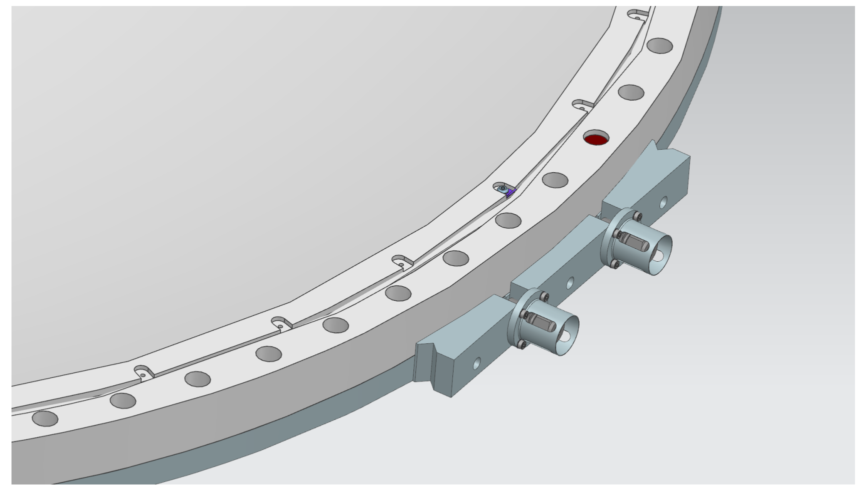




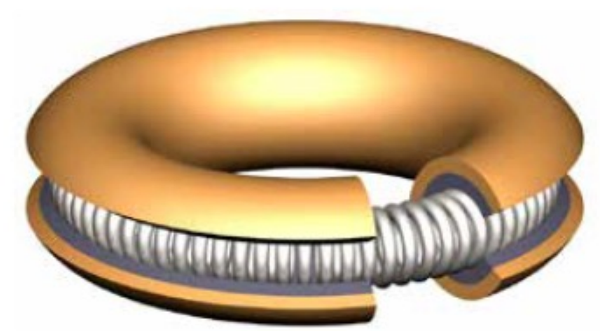
Helicoflex Seal

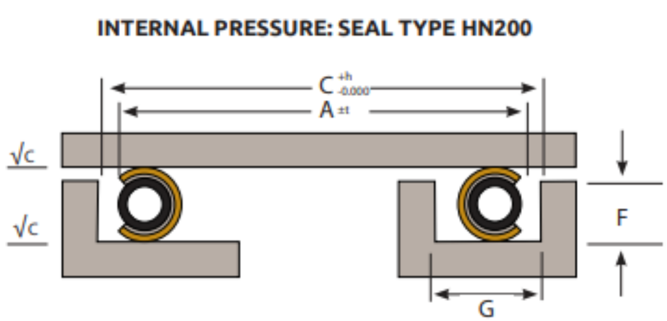
Seal Parameters:

- Specialized for Helium Sealing
- Cross Section: 0.276 in
- Diameter: 68.7in



- Manufacturer Specifications
  - Compression Force: 1542 lbs/in
    - w/ 80 Bolts = 4160 lbs/bolt
  - Max Operating Temp.: 392°F = 200°C
  - Groove Design parameters provided by manufacturer to ensure proper seal seating





Helicoflex Seal

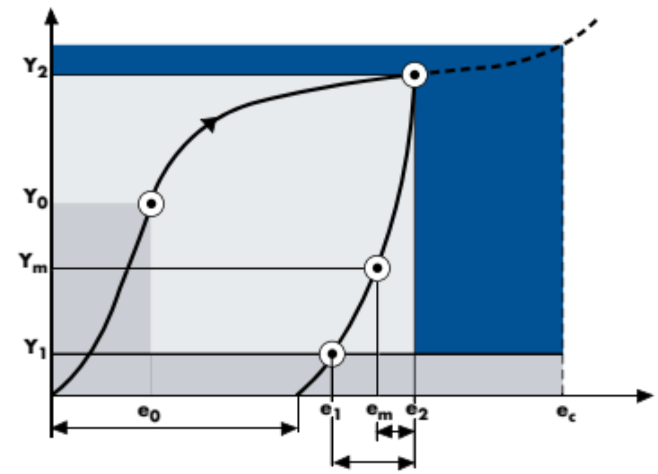
Charge 1

Compression Load Requirements:

- Manufacturer Catalogue located at docdb-31052

- Optimal sealing load (Y_2) = 1542 lbs/in
- Minimum sealing load (Y_0) = 660 lbs/in
- Minimum service load (Y_m) = 228 lbs/in
- Minimum sealing load after seating (Y_1) = 228 lbs/in

- Manufacturer claims Helium leak tight up to 10150 psi at 68°F (20°C) and 4060 psi at 392°F (200°C)



Jacket Material	HELIUM SEALING							BUBBLE SEALING				
	Cross Section	e_2	e_c	Y_2 lbs/inch	Y_1 lbs/inch	Pu68°F PSI	PuΘ392°F PSI	Y_2 lbs/inch	Y_1 lbs/inch	Pu68°F PSI	PuΘ392°F PSI	Max Temp °F
Aluminum	0.063	0.024	0.028	857	114	7250	N/A	514	114	5075	N/A	302
	0.075	0.028	0.033	914	114	7540	N/A	571	114	5800	N/A	302
	0.087	0.028	0.035	942	114	7685	N/A	600	114	5800	N/A	356
	0.098	0.028	0.035	999	114	7975	725	657	114	6090	725	428
	0.118	0.031	0.039	1056	143	7975	1450	742	114	6525	1450	482
	0.138	0.031	0.039	1085	143	7975	2030	799	114	6815	2030	482
	0.157	0.035	0.043	1142	143	8700	2465	857	114	7250	2465	536
	0.177	0.035	0.047	1199	143	8700	2900	914	114	7540	2900	536
	0.197	0.035	0.055	1256	171	9135	3190	971	143	7975	3190	572
	0.217	0.035	0.063	1313	171	9425	3480	1028	143	8265	3480	608
	0.236	0.039	0.071	1399	200	9715	3625	1113	171	8700	3625	644
	0.276	0.039	0.087	1542	228	10150	4060	1171	200	9425	4060	644
	0.315	0.039	0.102	1656	286	10440	4640	1285	228	9860	4495	680

CALCULATIONS ACCORDING TO CODES

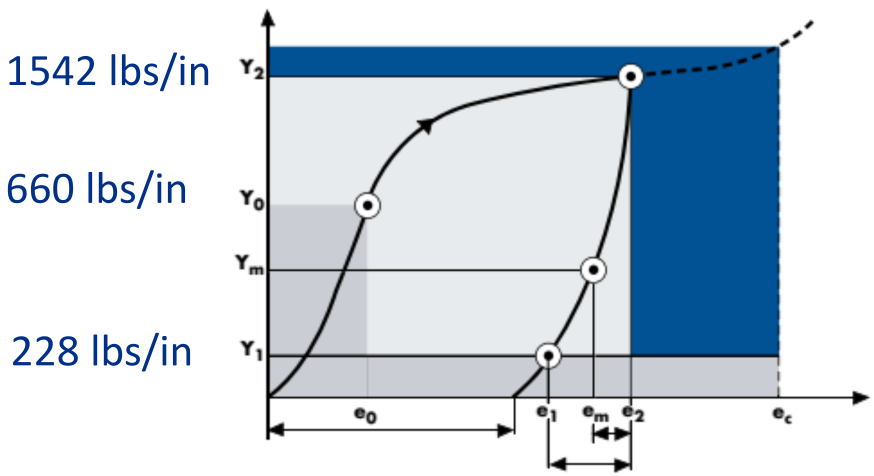
	A.S.M.E. Section VIII Division I	Technetics Group
Operating load	$Wm2 = n.b.G.y$	$Fj = n.Dj.Y_2$
Hydrostatic force	$H = n.\frac{G^2}{4}.P$	$F_F = n.\frac{(Dj)^2}{4}.P$
Minimum service load	$H_p = 2.b.n.G.m.P$	$Fm = n.Dj.Ym$ $Ym = Ym_1 = Y_1$; $Ym_2 = Y_2 \frac{P}{Pu\Theta}$ Use the greater of the two
Minimum tightening load to apply on bolts	$W =$ (1) W_{m2} (2) $H + Hp = W_{m1}$	$F_B =$ (1) Fj (2) $F_F + F_m = Fs$
	Use the greater of the two (1) or (2)	Use the greater of the two (1) or (2)

Helicoflex Seal

Charge 1, 2, 5

Seal Test 2016:

- Location docdb-981
- Conducted using test setup at Fermilab MI-8 service building
- At 660 lbs/in shows <1sccm
  - Requirement is 10 cc/min (200 ft^3/year)
- Proves minimum sealing pressure



Trial	Hydraulic pressure psi	Compressive load on seal pounds	leak rate sccm	He pressure in tank psi		Compressive load on seal per linear inch	percentage of Y2	percentage of Y1
1	200	15,708	820	3		131.50	9%	66%
2	400	31,416	205	5.3		262.99	17%	131%
3	600	47,124	36	5.3		394.49	26%	197%
4	800	62,832	13	5.35		525.98	34%	263%
5	1000	78,540	0	5.35		657.48	43%	329%

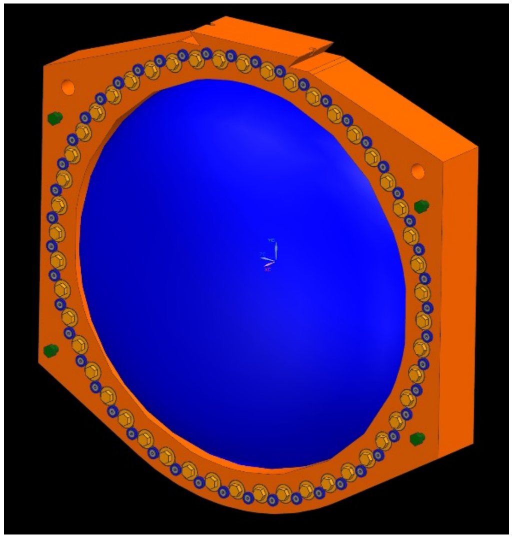
Helicoflex Seal

Charge 5

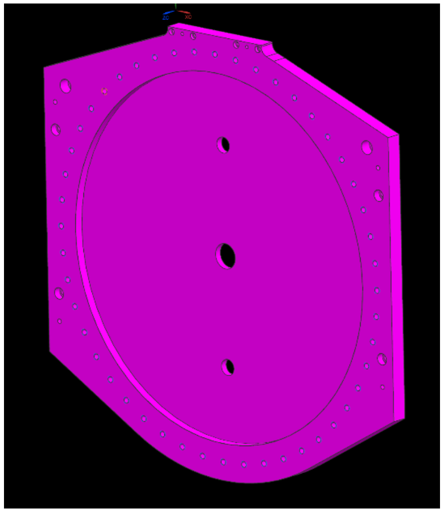
Rec. 5

Additional Seal Test:

- Seal test being conducted at MI-8 looking at additional parameters of sealing.
- Draft of pressure test located in docdb-31135



- 3 Tests:
  - Confirming torque requirements for seal compression in ideal parameters
  - Sealing to out of flatness sealing face to determine sealing force requirements
    - 0.032 Amplitude. Twice manufacturer specification
  - Ideal seal environment with thermal cycling using heat tape
    - Cycling between max expected temperature and ambient

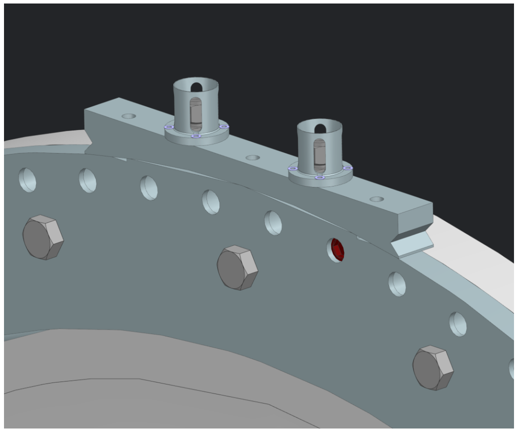


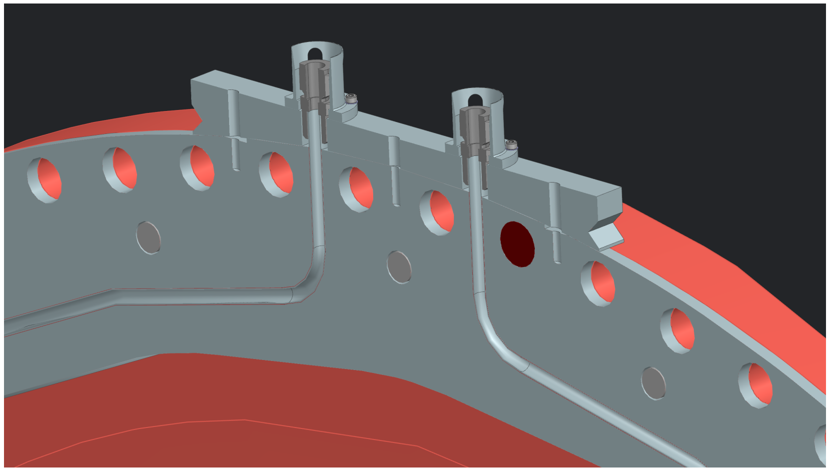
Fermilab

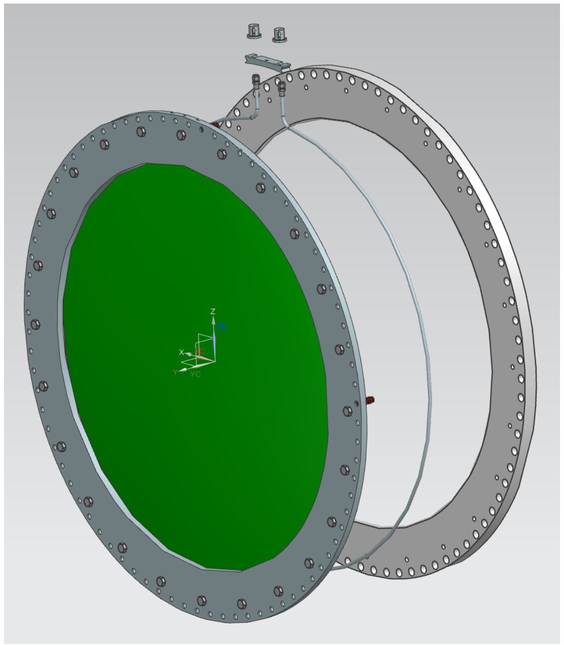
USDP Window Cooling Loop

Charge 2

- Cooling loop necessary to reduce heat in flange at 2.4 MW to keep Helicoflex seal within operating temperature.
- Cooling loop required to be removable to meet requirement of USDP Window being removable
- Utilizing Swagelok compression fittings proven in NuMI Horn operation
- Cooling lines only needed for 2.4 MW Operation







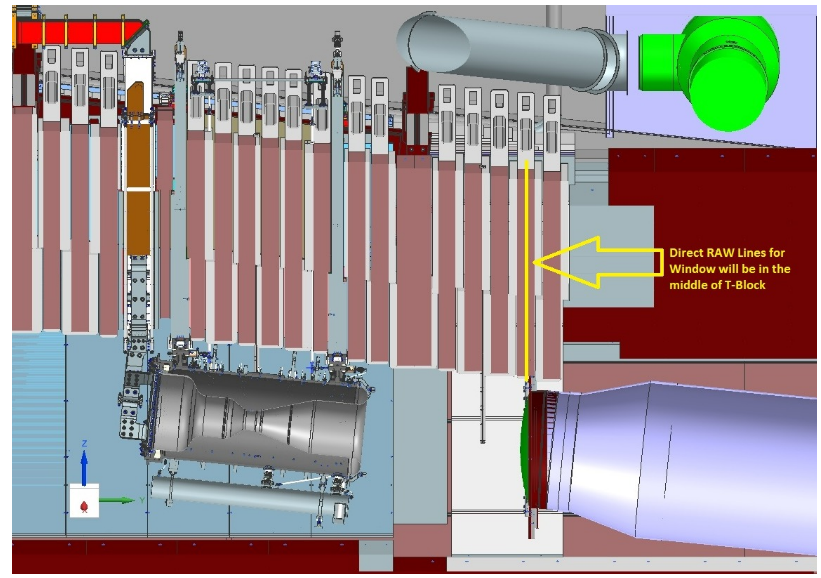
USDP Window Cooling Loop

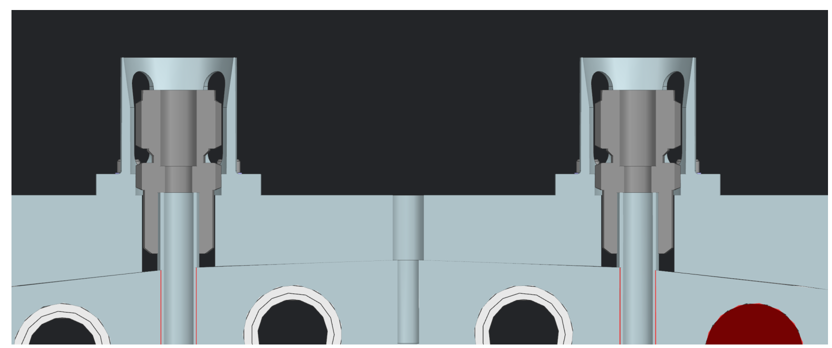
- RAW Lines reach window through labyrinthed penetrations in the above T-Block

- Characteristics:
  - Heat Load = 16500 kW
  - ΔT inlet to outlet = 10C
  - Flow Rate = 6.2 gpm
  - SS316 Piping

- Connection accessed from top of T-Block shielding
- Guide brackets on the top side of the window aid in aligning compression fittings
  - Same design used for the NuMI Horns

- RAW Piping Envelope drawing located docdb-31052





USDP Window Permanent Cooling Loop Discussion

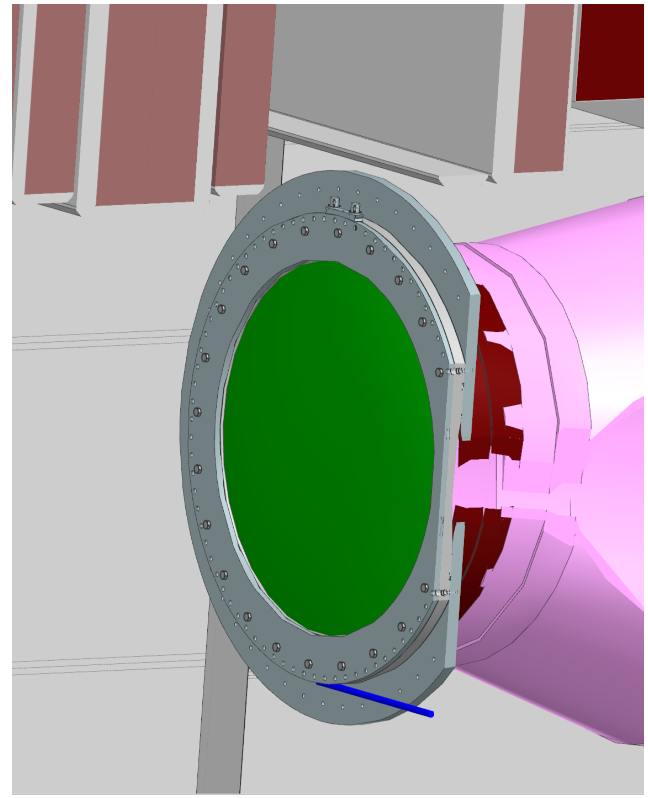
Charge 7

Rec. 6

- Per Technical Design Review of the Decay Windows, consideration was given to the addition of a permanent cooling loop on the USDP Snout Flange to provide more uniform temperature on sealing surface.
  - Full discussion of conclusion located in docdb-31052

- Decision is to not include this additional cooling loop.

- 1. Previous design used outdated thermal loading. New loading shows reduction in sealing area temperature by roughly 10C
- 2. The project has pushed for all systems with the potential to leak to be serviceable
- 3. Inclusion of a larger cooling loop that is to accommodate this recommendation would add substantial scope to the project to design a method of servicing the component



Fermilab

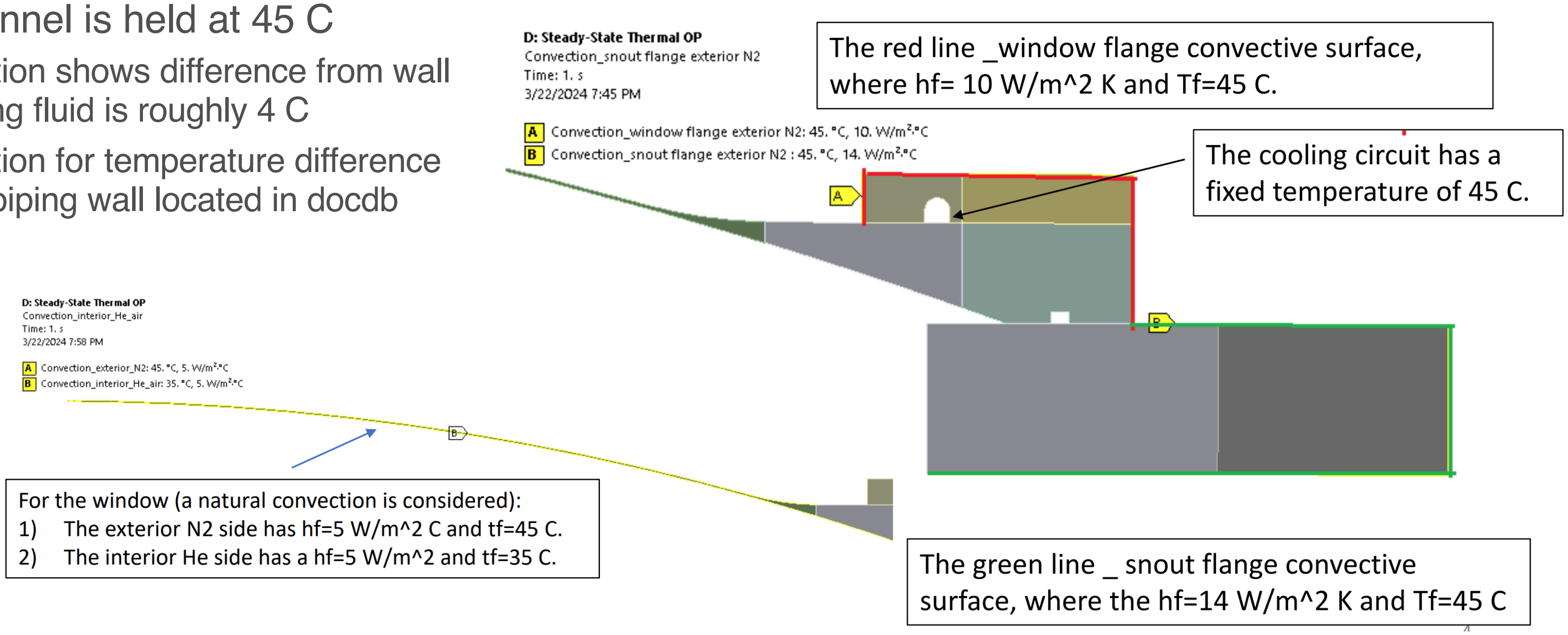
USDP Window Thermal/Structural Analysis

Charge 2

Rec. 2

- Overview
  - Updated from previous analysis with peer review recommended modifications

- Model and Boundary Conditions:
  - Model located TC: F10118812
  - Convection provided in docdb-28069
  - Cooling channel is held at 45 C
    - Calculation shows difference from wall to cooling fluid is roughly 4 C
    - Calculation for temperature difference across piping wall located in docdb 31132



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USDP Window Thermal/Structural Analysis

Charge 2

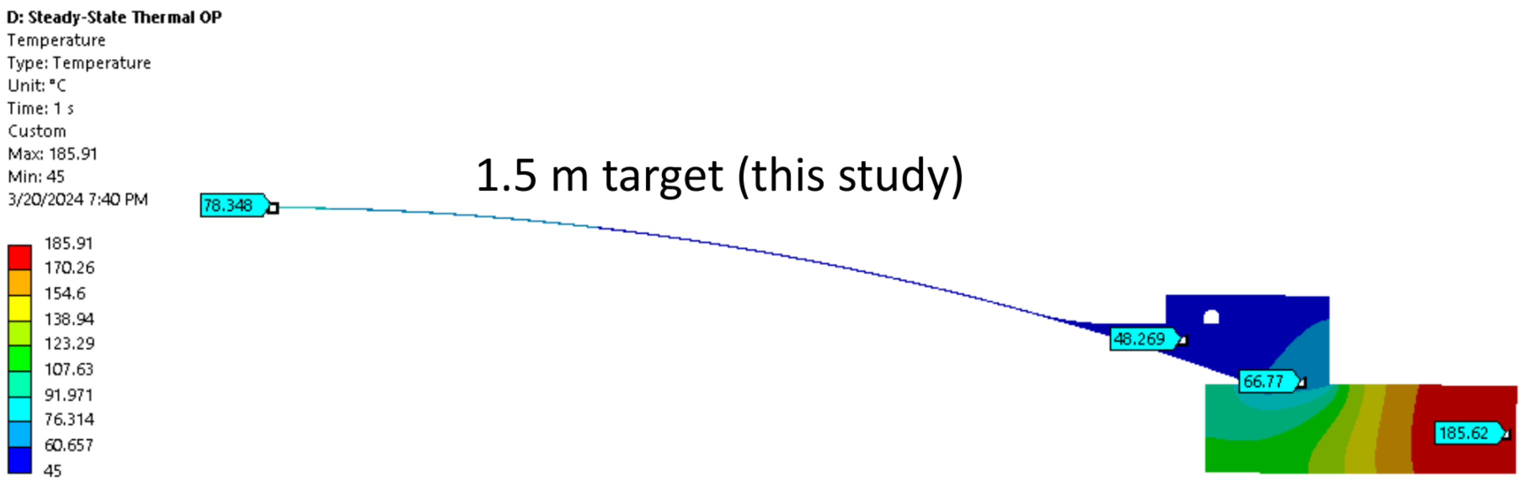
Rec. 2

- Thermal Results:
  - Successfully hold sealing surface within optimal operating conditions at all accident cases
  - Accident Cases:
    - 2 Pulses
      - Tmax = 225 C
    - 5 Pulses
      - Tmax = 241 C

Temperature Result

	Window (Al6061-t6)	Window flange (Al6061-t6)	Snout flange (SS304L)
OP T max (C)	78.4	72.7	186
After 2 accident pulses	225	No Effect	No Effect
After 5 accident pulses	241	No Effect	No Effect

Note:
1. ΔT=~0.675 C/per pulse for the normal operating case. It is very small.
2. ΔT=~134 C/per pulse for the accident (No target)case.

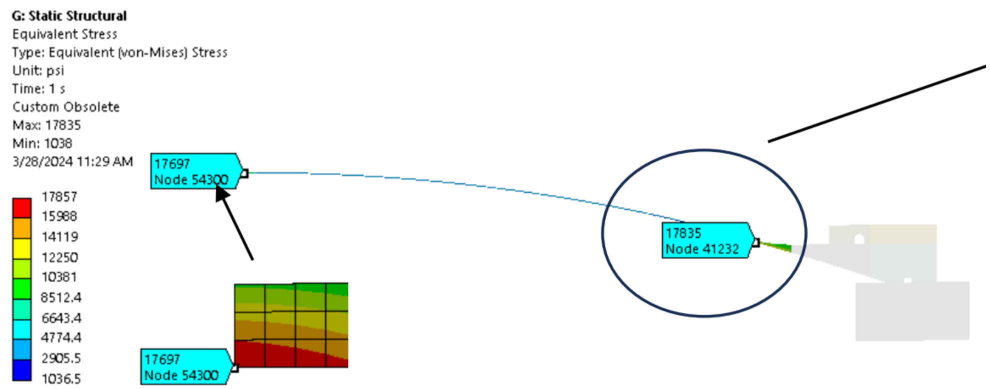


USDP Window Thermal/Structural Analysis

Charge 2

Rec. 4

- Structural Results:
  - Stresses are less than allowable for 2 pulse accident cases
- Accident Cases:
  - 2 Pulses:
    - Max Dynamic Stress = 17.1 ksi
  - 5 Pulses:
    - Max Dynamic Stress = 20 ksi
- ASME Allowable (ASME BPVC. II. D.C-2021, Part D, Table 5B):
  - Yield = 34.2 ksi
  - Ultimate = 42 ksi
- MIL-HDBK-5 (MIL-HDBK-5 SECTION 3.6.2, Edition 5G, for 6061 ALLOY):
  - Yield = 20.52 ksi
  - Ultimate = 21.884 ksi
- Analysis to be uploaded through TC and attached to AECOM FESHM 5031.5 note.
  - FESHM Note located docdb-23864



ructural

Stress Result

	Stress (5 psi + thermal)		Dynamic stress (5 psi + thermal)
OP Tmax=78 C	3.69 ksi at the window center R=0	17.7 ksi at R=~677 mm	
After 2 accident pulses Tmax=225 C	14.9 ksi (compression) at the window center R=0	17.8 ksi at R=~677 mm	~20 ksi (in compression)
After 5 accident pulses Tmax=241 C	17.7 ksi (compression) at the window center R=0	17.8 ksi at R=~677 mm	~17.1 ksi (in compression)

USDP Window Bolted Joint Study

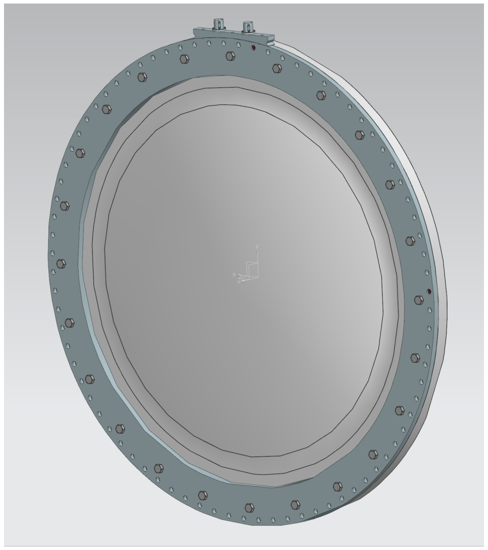
Charge 2

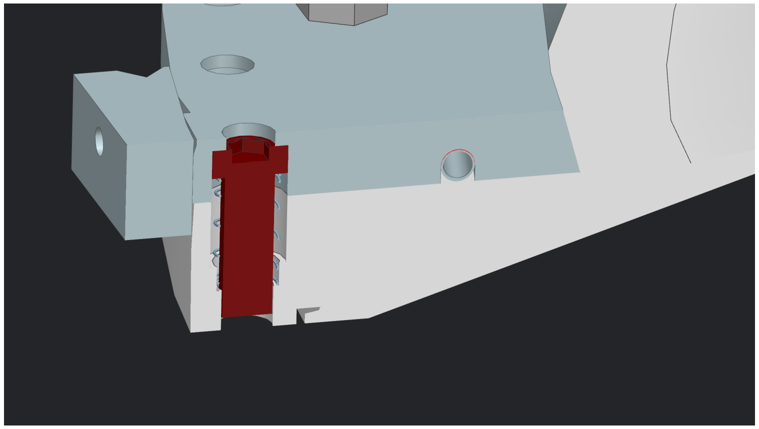
Rec. 4

- A bolted joint analysis was conducted to identify the required forces for clamping and effects of thermal expansion on the joint for bolt loosening and low-cycle fatigue

- Analysis located at docdb-
  - Analysis is in draft state and requires peer review before Technical Peer Review recommendation is considered met

- References:
  - Machinery's Handbook
  - Engineers Edge





USDP Window Bolted Joint Study

Charge 2

Rec. 4

Minimum Bolt Spacing for Gasket Compression:

- Minimum Force: 228 lbs/in
  - Minimum service load of Seal
- Maximum Force: 1542 lbs/in
  - Seating force of seal. Seal groove diameter further compression after seating is reached
- Safety factor of 3 used

- Minimum bolt spacing: 7.47 in

- Current Bolt Spacing: 2.7 in

$$C = \left[\frac{480(a/b)Et^3\Delta H}{13P_{min} + 2P_{max}}\right]^{1/4}$$

Where:

a = Width of cover / flange plate at seam (in)
b = Width of gasket (in)
C = Bolt spacing (in) (see illustration below)
E = Modulus of elasticity of cover / flange plate (lb/in^2)
$\Delta H = H_2 - H_1$ (in)
H_1 = Minimum gasket deflection (in)
H_2 = Maximum gasket deflection (in)
P_{min} = Minimum gasket pressure (lb/in^2)
P_{max} = Maximum gasket pressure (lb/in^2)
t = Cover / flange thickness (in)

USDP Window Bolted Joint Study

Charge 2

Rec. 4

Required Torque:

- Machinery's Handbook 30th edition
- Standard 70% yield preload
- Torque wrench uncertainty = 25%
- Allow for 10% preload loss due to local yielding

- Tensile Yield of Ti-6Al-4V = 128000 psi

- Calculated Preload = 13535.1 lbs
- Load required by Helicoflex for seating
  - 4160 lbs

- Required Torque = 60.1 ft-lbs

Tightening Method	Accuracy
By feel	±35%
Torque wrench	±25%
Turn-of-the-nut	±15%
Load indicating washer	±10%
Bolt elongation	±3-5%
Strain gages	±1%
Ultrasonic sensing	±1%

$$T_1 = P_B \times l \div 2\pi$$

$$T_2 = \frac{d_2 \mu_1 P_B}{2\cos\alpha}$$

$$T_3 = \frac{d+b}{4}\mu_2 P_B$$

$$T = P_B\left(\frac{l}{2\pi} + \frac{d_2\mu_1}{2\cos\alpha} + \frac{(d+b)\mu_2}{4}\right)$$

USDP Window Bolted Joint Study

Charge 2

Rec. 4

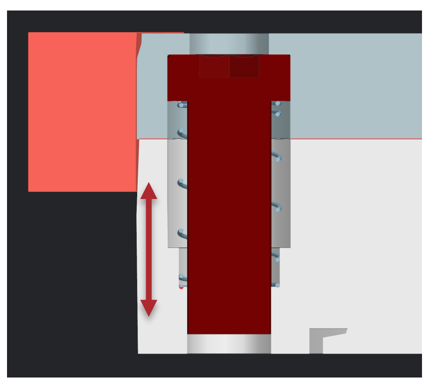
Change in preload due to thermal loading:

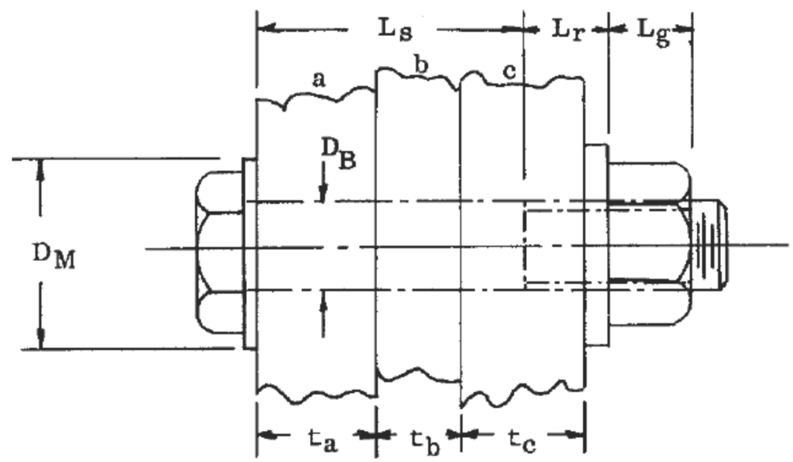
- Bell Helicopter Structural Design Manual
- Bolt load after temperature change from ambient temperature and the product of the net thermal expansions and combined internal stiffness
- Temp change of 41°C used taken from Ang Lee's Analysis

Eq. 5

$$P_T = \frac{(T - T_0)(\alpha_M t_M - \alpha_B L_B)}{\frac{1}{E_b}\left(\frac{t_s}{A_s} + \frac{t_r}{A_r} + \frac{t_g}{2A_r}\right) + \frac{t_m}{A_M E_M}}$$

- P_T = 224.4 lbs
- This force is adding to the preload 9375 lbs present in system. Change is not enough to loosen bolts





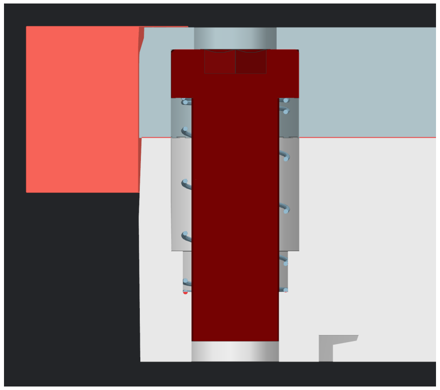
USDP Window Bolted Joint Study

Charge 2

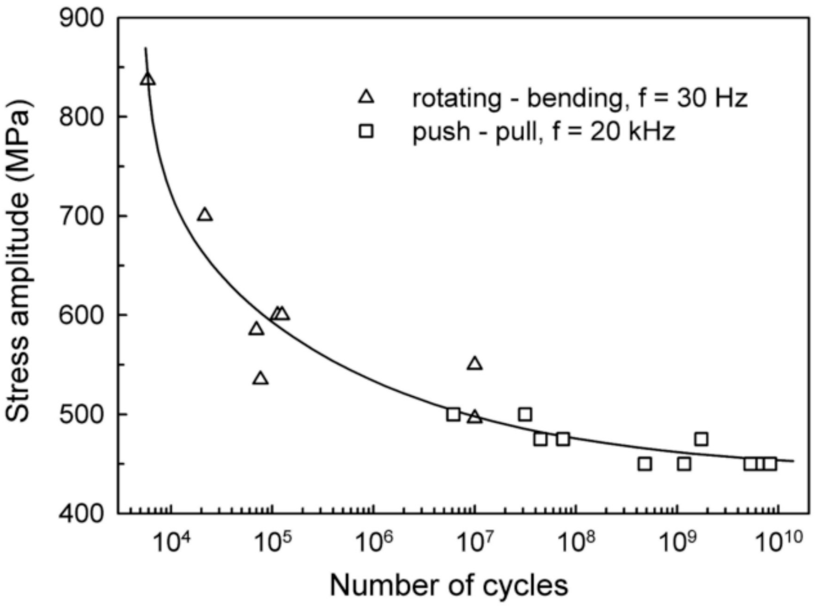
Rec. 4

Investigation for Low-Cycle Fatigue:

- Low cycle fatigue we are defining as 10^4 cycles or less from beam induced thermal expansion and contraction
- Stress from restricted thermal expansion equations
  - 2 systems analyzed
    - Restricted aluminum expansion
    - Reinforced Titanium threaded into SS flange
  - Total Stress Amplitude
    - σ = 94.14 MPa
- At 10^4 cycles, stress amplitude must be ~700 Mpa to induce fatigue failure



S-N Curve for Ti-6Al-4V



Fermilab

USDP Window Cost Estimates

Charge 2

Rec. 4

Cost:

- Fabricated Pieces = $60332.6
- Hardware = $3871.02
- Tungsten Disulfide Coating = $28800

Total = $93003.62

Item	Quantity	Cost/per	Total
3/4-16 UNF Grade 5 Titanium Bolts	80	37.43	$2,994.40
S-1570 304 Stainless Steel Compression Spring	80	5.7	$456.00
Metric 8.8 Hex Head Cap Screws Clear Zinc Finish, DIN 933	24	9.93	$238.32
M4 Socket Head Cap screws, Stainless Steel A2 (18-8)	8	1.7	$13.60
1/4" LIGHT BELLEVILLE WASHER 4L42177, 17-7PH SS	8	0.6	$4.80
Swagelol 1/2" Male Pipe Weld Fitting	2	21.95	$43.90
7m 1/2" Stainless Steel Tubing	1	120	$120.00
		Total	$3,871.02

DESCRIPTION	QTY	COST EACH	TOTAL
#F10118811 Frame - material, machine and deliver (no coating)	1	47,417.00	47,417.00
#F10203758 Window - material, machine and deliver (no coating)	1	12,915.60	12,915.60
Delivery: 6-8 weeks			

USDP Window Installation

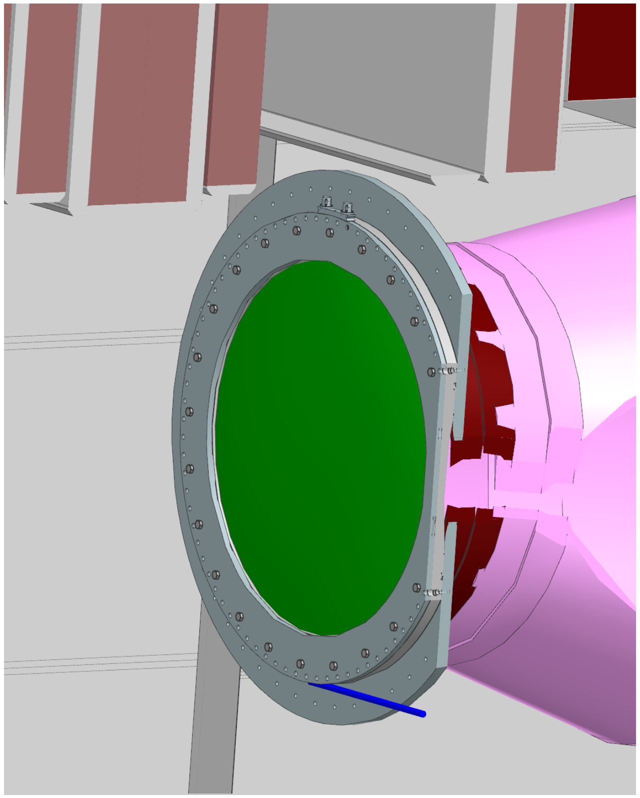
Charge 2

Rec. 4

- Installation will be conducted using the USDP Window Remote Exchange Mechanism. As such, a full definition on installation requirements or procedures is not able to be conducted until the FDR of the Remote Exchange Mechanism

- Installation Plan:
  - Phase 1 (Preparation):
    - Window will be retrieved from storage. Perform pressure test and check for defects
    - Mechanism will be retrieved and moved to high bay. Electrical and controls connections made and mechanical assemblies tested
  - Phase 2 (Window Loading):
    - Window is loaded onto mechanism
  - Phase 3(Installation of Window):
    - Window is installed onto flange

- Preliminary Installation Procedure located docdb-31052
- Full installation procedure will be reviewed at Exchange Mechanism FDR



USDP Window QA/QC

Charge 2

Rec. 4

- Draft Located docdb-31077

- QC Procurement
  - Vendor fabrications shall be procured with dimensional inspection reports, to be spot checked upon receipt
- QC Fabrication
  - An engineer or designated inspector will spot check these in-process measurements
  - Fabrication records will be kept by the engineer
  - Cooling loop will be pressure tested and certified
- QC Installation
  - Beamline is responsible with coordinating with NSCF for in process quality control measurements to meet design requirements for the USDP Window
  - Beamline will coordinate with NSCF to conduct installation of USDP Window utilizing the USDP Window Remote Exchange Mechanism

Questions?

Helicoflex Seal

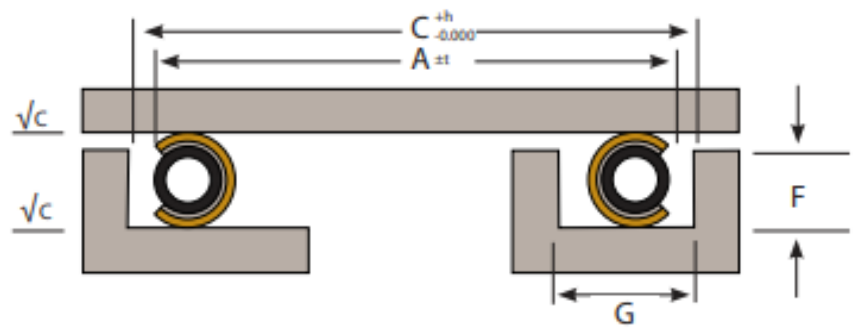
Charge 2

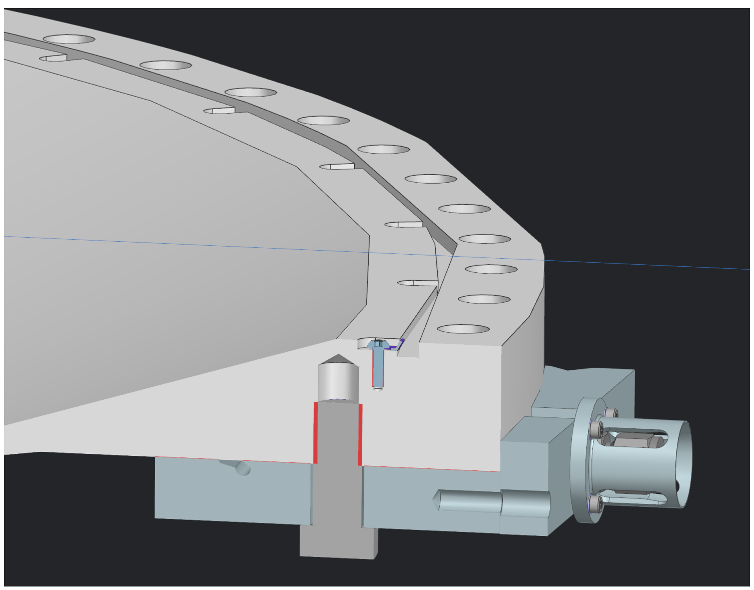
Groove Design:

- Depth = 0.237 ± 0.005in
- Width = 0.354
- Groove Finish = 32

- Catalogue listed in Docdb-31052

INTERNAL PRESSURE: SEAL TYPE HN200





	SEAL			Pressure < 300psi	Pressure ≥ 300psi	GROOVE		
Jacket Material	Free Height	Installation Compression e2	Seal Diameter Range	Diametral Clearance X	Diametral Clearance X	Groove Depth F	Groove Width (Min.) G	Groove Finish RMS
Aluminum	0.063	0.024	0.500 to 4.000	0.024	0.012	0.039 +/- 0.003	0.111	32-125 Contact us at sales@technetics.com for recommendation
	0.075	0.028	0.625 to 6.000	0.028	0.012	0.047 +/- 0.003	0.131	
	0.087	0.028	0.750 to 10.000	0.028	0.012	0.059 +/- 0.003	0.143	
	0.098	0.028	0.875 to 15.000	0.028	0.012	0.070 +/- 0.003	0.154	
	0.118	0.031	1.000 to 20.000	0.031	0.012	0.087 +/- 0.004	0.180	
	0.138	0.031	1.250 to 25.000	0.031	0.020	0.107 +/- 0.004	0.200	
	0.157	0.035	1.750 to 30.000	0.035	0.020	0.122 +/- 0.004	0.227	
	0.177	0.035	2.000 to 40.000	0.035	0.020	0.142 +/- 0.004	0.247	
	0.197	0.035	3.000 to 50.000	0.035	0.020	0.162 +/- 0.004	0.267	
	0.217	0.035	4.000 to 50.000 +	0.035	0.020	0.182 +/- 0.004	0.287	
	0.236	0.039	5.000 to 50.000 +	0.039	0.028	0.197 +/- 0.005	0.314	
	0.276	0.039	6.000 to 50.000 +	0.039	0.028	0.237 +/- 0.005	0.354	
	0.315	0.039	8.000 to 50.000 +	0.039	0.028	0.276 +/- 0.005	0.393	

USDP Window Bolted Joint Study

Charge 2

Rec. 4

Stress From Differential Thermal Expansion:

$dl = \alpha\, l_o\, dt$ (1)

where

dl = elongation (m, in)

α = temperature expansion coefficient (m/mK, in/in ^oF)

l_o = initial length (m, in)

dt = temperature difference (^oC, ^oF)

$\varepsilon = dl / l_o$ (2)

where

ε = strain - deformation

$E = \sigma / \varepsilon$ (3)

where

E = Young's Modulus (Pa (N/m^2), psi)

σ = stress (Pa (N/m^2), psi)

$\sigma_{dt} = E\, \varepsilon$

$= E\; dl / l_o$

$= E\, \alpha\, l_o\, dt / l_o$

$= E\, \alpha\, dt$ (4)

where

σ_{dt} = stress due to change in temperature (Pa (N/m^2), psi)