Fermilab

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LBNF Primary Beam Window and Cartridge Design Review

Dave Pushka

LBNF Primary Beam Window and Cartridge Design Review

November 2020

Charge Questions:

1. Does the final design meet the requirements of the beamline components?
2. Does the window meet the FESHM safety requirements? Have all ESH and Quality issues been identified and planned for?
3. Does the window meet the beam aperture requirements for both normal operations and beam scans?
4. Does a viable plan exist for replacing the window in accordance with ALARA principles?
5. Are the interfaces identified and documented appropriately?
6. Is the final cost and schedule reasonable? Are procurements well planned?
7. Is the installation thought out and planned for? Potential problems identified?
8. Are the documents (requirements, specifications, schematics, engineering notes, procedures, and drawings) at the appropriate level for a final design?

Contents of Talk

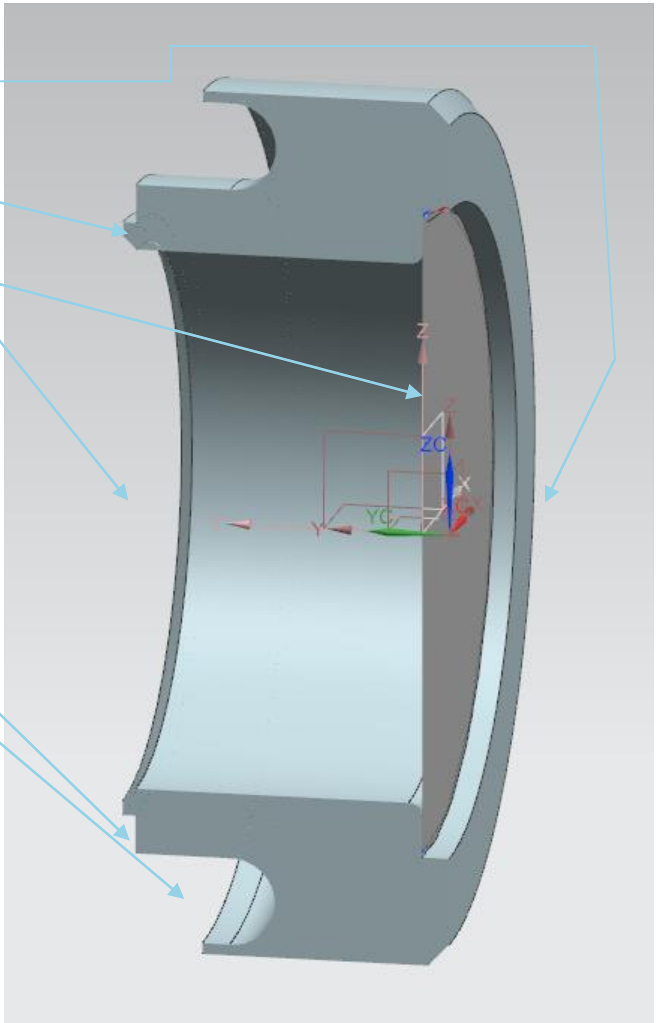
- Primary Beam Window & Cartridge Overview
- Primary beam window thermal analysis and temperatures
  - (As required by FESHM 5033.1)
- Cartridge Alignment Capabilities
- Charge Questions 1 to 8

Primary Beam Window

- Vacuum on the left hand side
- 3 psig on the right hand side
- Housing is 304 stainless steel
- Membrane is beryllium
- Fixed restraint
- Location for cooling tubing

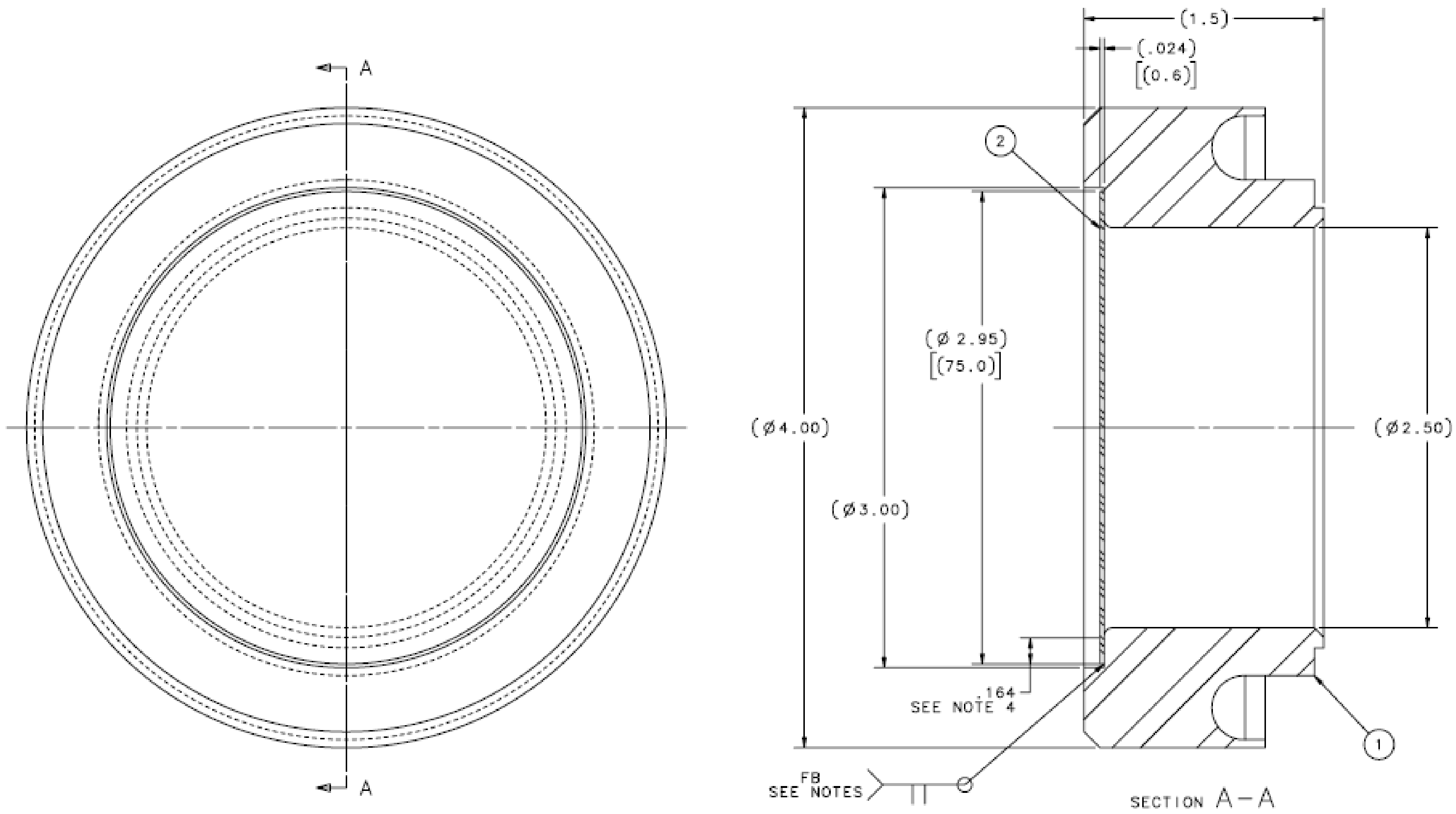
- Membrane inner diameter = 63.5 mm (~2.5 inches), outer diameter = 74.93 mm (2.95 inches)
- Hole thru housing is 63.5 mm (2.5 inches) in diameter
- Membrane thickness = 0.024 inches (0.61 mm) Per FESHM 5033.1
- Designed for 18.7 psi delta P Target Chase is pressurized at 4 psig max)

- See Fabrication Dwg in TC F10123128 (see next slide).



DESCRIPTION: LBNF PRIMARY BEAMLINE WINDOW - WINDOW BRAZING
PROJECT: LBNFBeamline
CATEGORY: ASSEMBLY

REV	REVISION CONTROL DOCUMENT	DATES	SIGNATURES
-	F10136777---RCD		DRAWN
			APPROVED



NOTES:

1. ASSEMBLY MUST BE CLEAN AND FREE OF CHIPS, GREASE AND OTHER CUTTING FLUIDS.
2. BRAZE MATERIAL COPPER/SILVER/TIN IS ACCEPTABLE
3. 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.
4. BRAZE ALLOY BOND BETWEEN SS AND Be FOIL MUST BE 100% CONTINUOUS WITH NO VOIDS OR POROSITY AND COVER THIS RADIAL ZONE.

ITEM	FERMI NO	PART NAME	QTY
2	F10134196	LBNF PRIMARY BEAMLINE WINDOW - MEMBRANE	1
1	F10123128	LBNF PRIMARY BEAMLINE WINDOW - HEAT SINK	1

UNLESS OTHERWISE SPECIFIED

±.X	±.XX	±.XXX	±X/X	±X°
.1	.02	.005	1/16	1°

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

DRAWN	D.HURD	DATE	26-Mar-2020
CHECKED	G.WAVER	DATE	27-Mar-2020
APPROVED	D.PUSHKA	DATE	27-Mar-2020

USED ON: F10136776
MATERIAL: SEE PARTS LIST
GROUP: Accelerator Mechanical Support | CAGE CODE: 0U5R8

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

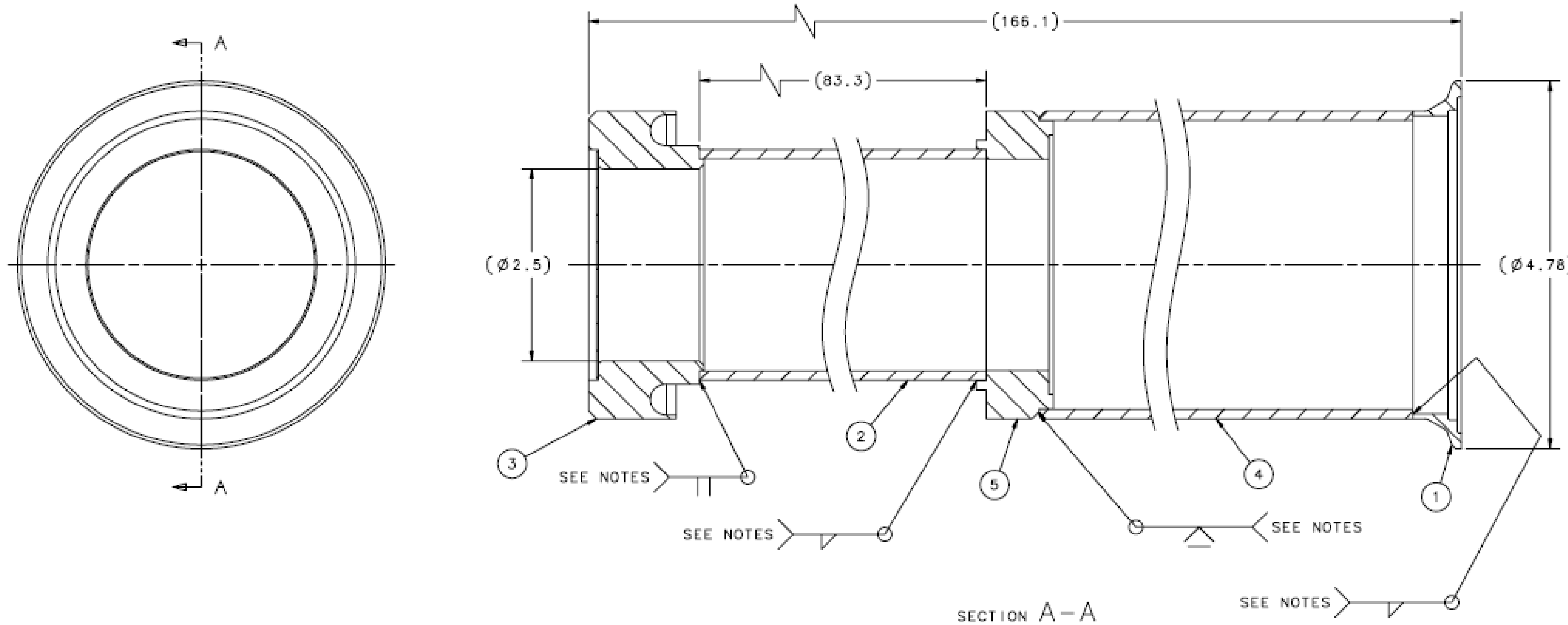
NAME: LBNF PRIMARY BEAMLINE WINDOW - WINDOW BRAZING

SCALE	SIZE	DRAWING NUMBER	SHEET	REV
2:1	C	F10136777	1 of 1	-

TEMPLATE VERSION: 2018.12.03

DESCRIPTION: LBNF PRIMARY BEAMLINE WINDOW - SLEEVE WELDMENT
PROJECT: LBNFBeamline
CATEGORY: WELDMENT

REV	REVISION CONTROL DOCUMENT	DATES		SIGNATURES
A	F10136776-A-RCD	21-Oct-2020	DRAWN	D.HURD
		23-Oct-2020	APPROVED	D.PUSHKA



NOTES:

1. ALL WELDING SHALL BE IN ACCORDANCE WITH ANSI/AWS D1.6. (STANDARD ULTRA HIGH VACUUM PRACTICE)
2. ALL CONTINUOUS WELDS TO BE VACUUM LEAK TIGHT.
3. HELIUM LEAK TEST SHALL BE PERFORMED WITH A MINIMUM DEMONSTRATED SYSTEM SENSITIVITY OF 1 X 10^{-9} STANDARD CC PER SECOND OF HELIUM USING A CALIBRATED LEAK. (A)

   WELD JOINTS SHALL BE BAGGED AND FLOODED WITH HELIUM AND THE HELIUM SHALL REMAIN FOR A PERIOD OF TIME EQUAL TO OR GREATER THAN THREE TIMES THE SYSTEM RESPONSE TIME.

   ALL INDIVIDUAL LEAKS GREATER THAN 1 X 10^{-9} STANDARD CC HELIUM PER SECOND SHALL BE REPAIRED AND RE-TESTED.

   SUM OF ALL LEAKS MUST BE LESS THAN 5 X 10^{-9} STANDARD CC HELIUM PER SECOND.

   HELIUM LEAK TESTING WILL BE OBSERVED BY FERMILAB STAFF.

   VENDOR IS RESPONSIBLE FOR PROVIDING MASS SPECTROMETER, HELIUM AND CALIBRATED LEAK.

ITEM	FERMI NO	PART NAME	QTY
5	F10147315	LBNF PRIMARY BEAMLINE WINDOW - MESH TO TRANSITION BRAZE	1
4	F10147311	LBNF PRIMARY BEAM WINDOW - UPSTREAM TUBE	1
3	F10136777	LBNF PRIMARY BEAMLINE WINDOW - WINDOW BRAZING	1
2	F10047527	LBNF PRIMARY BEAMLINE WINDOW - DOWNSTREAM TUBE	1
1	F00359521	4 INCH QUICK DISCONNECT FLANGE	1

UNLESS OTHERWISE SPECIFIED

±.X	±.XX	±.XXX	±X/X	±X°
.1	.02	.005	1/16	1°

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

THIRD ANGLE PROJECTION

DRAWN	D.HURD	DATE	26-Mar-2020
CHECKED	G.WAVER	DATE	27-Mar-2020
APPROVED	D.PUSHKA	DATE	27-Mar-2020

USED ON: F10047628

MATERIAL: SEE PARTS LIST

GROUP: Accelerator Mechanical Support | CAGE CODE: 0U8R8

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

NAME: LBNF PRIMARY BEAMLINE WINDOW - SLEEVE WELDMENT

SCALE	SIZE	DRAWING NUMBER	SHEET	REV
1:1	C	F10136776	1 of 1	A

TEMPLATE VERSION: 2018.12.03

FESHM 5033.1 Thermal Analysis Requirements

1.1 Loads

a) In addition to vacuum loading, window design shall take into account any other load which may affect window function. These loads include, but are not limited to, those resulting from variation of pressure on the window (due to normal operation or possible faulty procedure), as well as all <u>relevant effects of beam deposition such as thermal loading</u>, cyclic mechanical shock due to very brief, high intensity beam pulsing, the number of cycles that the window experiences, corrosion which may be due to high ionizing radiation, and materials degradation from long-term beam exposure. Considering these effects may lead to additional analyses or tests related to creep or fatigue failure of the window.

Thermal Analysis

- A series of thermal analyses were performed to evaluate the effectiveness of cooling the perimeter of the window with liquid cooling at two temperatures (35 C & 7 C) and the case where the boundary condition at the liquid cooling interface was perfectly insulated.
- Three different convective boundary conditions were set at the surface of the window of 5, 25, and 250 W/m2-K to evaluate the effect of the cooling from the target pile nitrogen circulation system.
- Energy deposition in the window was provided by Diane Reitzner on a per proton basis using MARS. Proton intensity for 2.4 MW beam was used in the FEA.

Cooling of energy from beam heating

- Analysis Performed by Ingrid Fang using Edep from Diane Reitzner

Table 3 - Cooling Conditions 1 to 9

	film coefficient w/(m^2-k) at room temp 22C	liquid cooling	liquid cooling temp
case1	5 (natural convection)	on	35C
case2	5(natural convection)	off	n/a
case3	5(natural convection)	on	7C
case4	25(low end forced convection)	on	35C
case5	25(low end forced convection)	off	n/a
case6	25(low end forced convection)	on	7C
case7	250 (high end forced convection)	on	35C
case8	250 (high end forced convection)	off	n/a
case9	250 (high end forced convection)	on	7C

Thermal Results at the Center of the Membrane:

	beam on	beam off	Delta T	Average
case1	95.1C	43.5C	51.6C	69.3C
case2	90.1C	38.4C	51.7C	64.25C
case3	68C	16.3C	51.7C	42.15C
case4	93.3C	41.6C	51.7C	67.45C
case5	87.2C	35.6C	51.6C	61.4C
case6	69C	17.4C	51.6C	43.2C
case7	83C	31.4C	51.6C	57.2C
case8	79.2C	27.5C	51.7C	53.35C
case9	74C	22.3C	51.7C	48.15C

Note there is no difference in Delta T in all cases. And that the liquid cooling at 35C should not be considered. The membrane temperature is reversed in case 9 compared to Cases 3&6. This means the high end forced convection should be avoided when liquid cooling is set at 7C. Furthermore, there is almost no difference in temperature with natural convection or low end forced convection in Cases 3&6

Cooling, Key Results from Ingrid's Analysis:

- The differences in temperature during the beam cycle remain constant in all Cases 1 to 9.
- When the liquid cooling is absent, the membrane temperature is the lowest with the high end forced convection in Case8.
- When the liquid cooling is applied at 7C, the membrane temperature is almost the same under the natural convection or the low end forced convection in Case3 and Case6.
- When the liquid cooling is applied at 7C, the high end forced convection should be avoided since the membrane temperature is reversed in Case9.
- And all in all, the liquid cooling at 35C should not be considered in Case1, Case2 and Case7.

- Note a peer review of Ingrid's work was performed by Zhijing Tang, a FEA and analysis expert in PPD.

Cooling – Conclusions:

- LCW is at about 35 C and should not be considered further as a cooling alternative.
- Convection Coefficient for the N2 in the target Chase has not been calculated as the CFD has not been performed.
  - Will likely be in the 5 to 25 W/m^2-K range
- Case 5, (25 W/m2-K) convection, without liquid cooling provides a temperature of about 87 C.
- Case 2 90 C with 5 W/m2-k convection (natural conv, no liquid cooling).
- Case 6, Liquid Cooling at 7 C (with low end forced convection) Only Lowers the temperature by about 18 C (lowers by 32 F) in the center of the membrane.
- Adding Liquid cooling does not seem worth the effort (and cost to put in a low temperature liquid cooling source).
- A CR to remove liquid cooling from the project scope has been initiated.

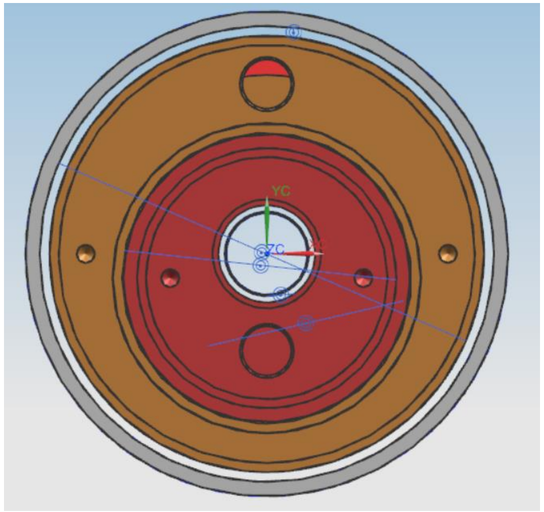
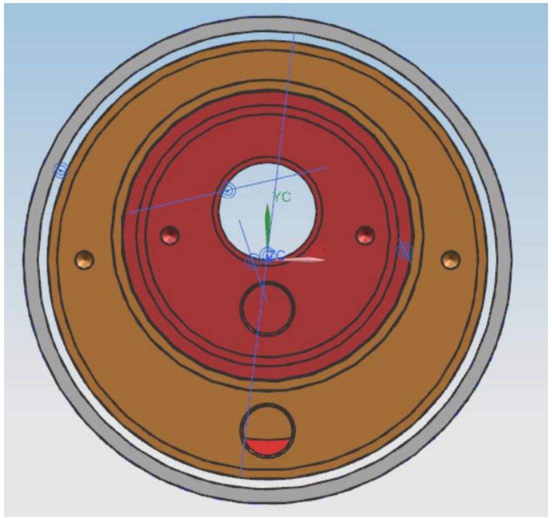
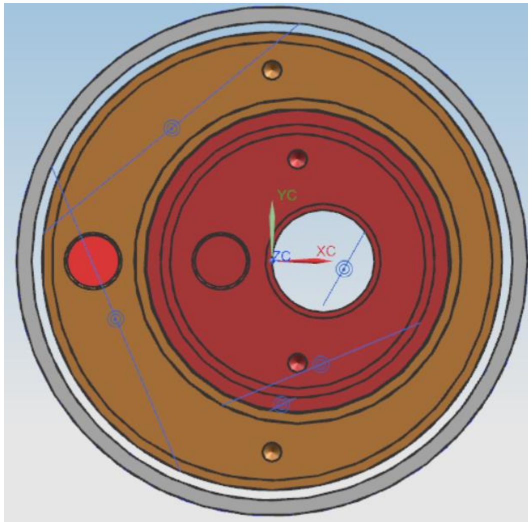
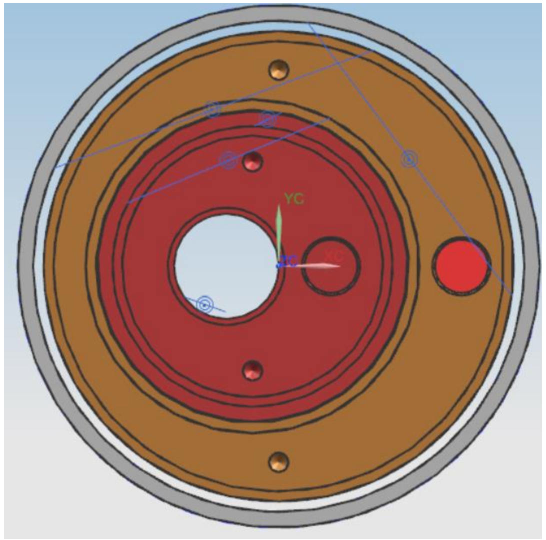
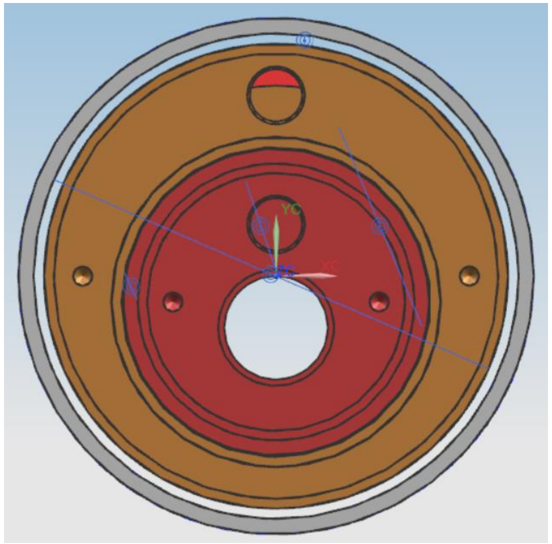
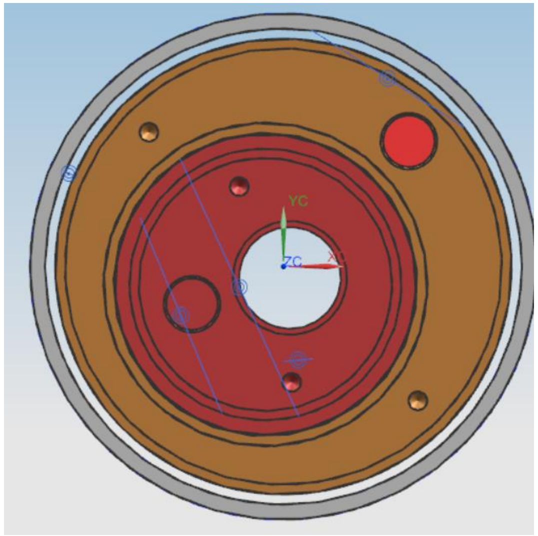
Corrosion considerations:

- One side of the window is exposed to beam line quality vacuum while the other side is exposed to the nitrogen atmosphere of the target chase.
- The choice to use nitrogen in the target chase (instead of air) was made to reduce corrosion experienced at NuMI to all components, including the primary beam window.
- Since corrosion issued for the NuMI window do not seem to drive window lifetime, and the LBNF environment should be more benign due to the nitrogen atmosphere, the FESHM requirement to address corrosion issues has been met.

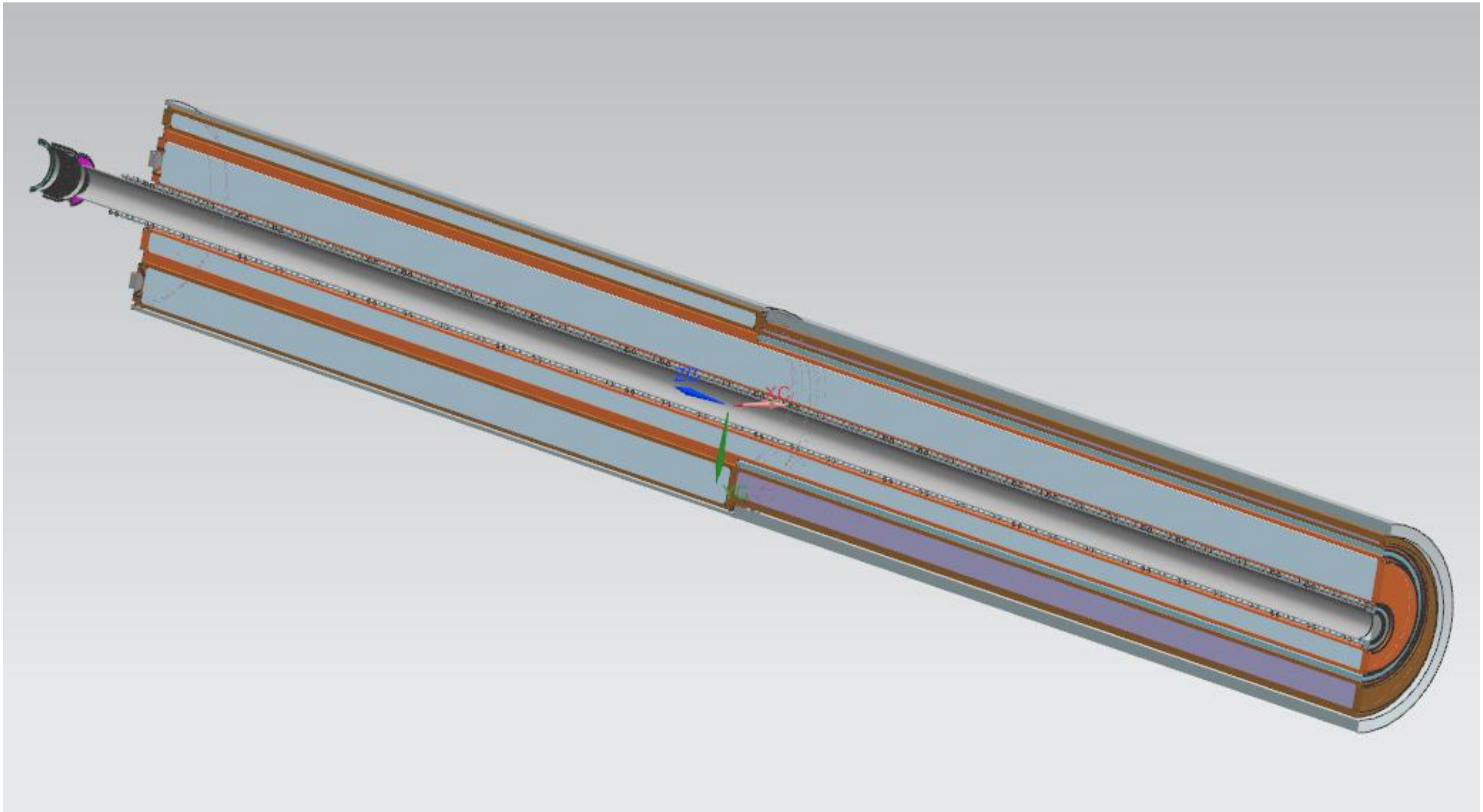
Cartridge:

- The cartridge is an assembly intended to fill the space around the hole provided by CF between the PBE and the target chase.
- It allows the beam pipe (and the window attached to it) to be fine tuned to be positioned to account for:
  - Civil Construction location tolerances (Gross adjustments)
  - Settlement of the building and enclosures over time (long term).
  - Minor changes to the beam optics (long term).
- Gross adjustment (to address CF construction tolerances) are addressed when the cartridge is installed in the hole. This allows transverse and angular position adjustments.
- Typical long term adjustment range appropriate for this application is plus or minus one inch (25 mm) in each direction (up-down, left-right).
- Rotations about the vertical axis and the horizontal axis (perpendicular to the beam direction) are not required after the initial cartridge installation.

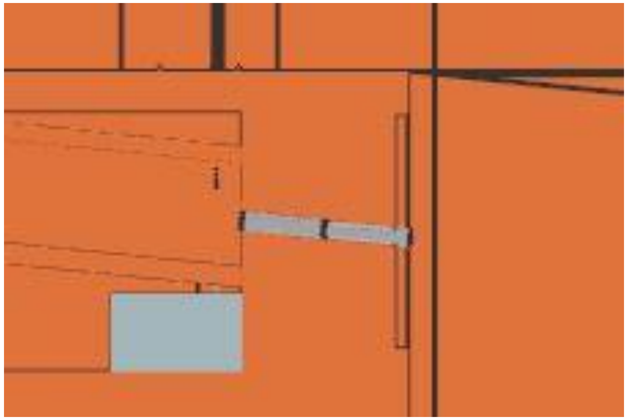
Cartridge: Eccentrics allow transverse positioning

Cartridge Made from Steel Tubes, Filled with Marble Fines



Cartridge Installed in Pipe Sleeve Provided by CF



- Cartridge Grouted in Place post Beneficial occupancy.
- Any angular alignment adjustments performed before grouting
  - Account for Civil Construction Tolerances
  - Account for Settling
  - Account for minor beam trajectory changes
- After Grouting, no additional angular adjustments are easily performed.
- Transverse Adjustments on the order of Plus or Minus 1 inch are always possible from the Pre-target Side.
- These adjustments are made from the PBE end where the radiation environment is less sever than the target hall end.

Q1: Does the final design meet the requirements of the beamline components?

- Yes.
- Requirements for the primary beam window imaged from the requirement are shown to the left:

id	Artifact Type	Name	Primary Text
1231	Requirement	Primary Beam Window - replacement	Primary beam window shall be replaceable consistent with ALARA.
1232	Requirement	Primary Beam Window - best practices	Primary beam window shall incorporate best practices to maximize lifetime.
1233	Requirement	Primary Beam Window - leak rate	Primary beam window leak rate shall be consistent with maintaining a beam transport quality vacuum in the primary beam transport line.
1234	Requirement	Primary Beam Window - beam transparency & FESHM	Primary beam window shall be as transparent to the proton beam as is use of conventional beryllium alloy membrane material allow while meeting FESHM 5033.1 requirements.

- The primary beam people (Phil Schlabach and Kevin Duel) have seen and reviewed this design several times (most recently September 8th 2020) and conclude it meets the primary beam requirements, including the aperture needed for beam scans.

Q2a: Does the window meet the FESHM safety requirements?

- FESHM 5033.1 applies to thin vacuum windows
- Key Engineering Note Calculation shown at right:
  - EN04530 in Teamcenter has these calculations as required by 5033.1
- Note Uniform pressure includes additional pressure from N2 in target chase.
- 5033.1 Required Thermal analysis performed and documented in DUNE docdb 20503
- This meets FESHM 5033.1

	A	D
1		
2		
3	**Per FESHM 5031& TM-1380:**	Beryllium
4	**For Rigid Materials, t> 0.003 inches**	LBNF
5	Diameter, mm (to the inner edge of support)	66.97472
6	Diameter, inches	2.64
7	Uniform Pressure, q (psi)	18.7
8	Radius of Window, a (inches)	1.318
9	Material	S200FH Beryllium
10	Young's Modulus, E (psi)	44,000,000
11	**Chosen Window Thickness, t (inches)**	**0.024**
12	**Chosen Window Thickness, t (mm)**	**0.6096**
13	Poisson's Ratio, v	0.06
14	K1 = 5.33/(1-v^2)	5.35
15	K2 = 2.6 / (1-v^2)	2.61
16	K3 = 2/(1-v)	2.13
17	K4 = 0.976	0.976
18		
19	Yield Stress, Fy (psi)	44,000
20	Ultimate Stress, Fu (psi)	60,000
21	Allowable Stress, S (psi) based on Material	30,000
22	Stress from E*(t/a)^2 * [K3*(y/t) + K4*(y/t)^2]	24,305
23	Check if Stress from Geometry > Material Allowable Stress	thickness ok
24		
25		
26	**Deflection, y (inches) {trial value}**	**0.0147**
27		
28	qa^4/Et^4	3.87
29	K1*(y/t) + K2*(y/t)^3	3.87
30	difference (Use goal seek to set this value to zero by changing the deflection in row 26)	0.000
31	**DEFLECTION, in**	**0.0147**
32	t/2	0.0120
33	Thin Criteria Met (y > t/2)	yes
34		
35		
36	Drawing or F number	F10134196

Q2b: Have all ESH and Quality issues been identified and planned for?

- Building Primary beam vacuum windows is well established.
  - Window data base includes approximately 76 windows
  - All existing drawings studied as part of this design effort.
- LBNF window process based on NuMI / NOvA / ANU windows.
- QA plan includes CT scans of a completed window
  - This has become a standard practice.
  - Included in cost and schedule

CT scan results for a titanium vacuum window brazed to a stainless steel conflat made by Omley Industries showing defects in the braze. Window size similar to the LBNF window.

Q3: Does the window meet the beam aperture requirements for both normal operations and beam scans?

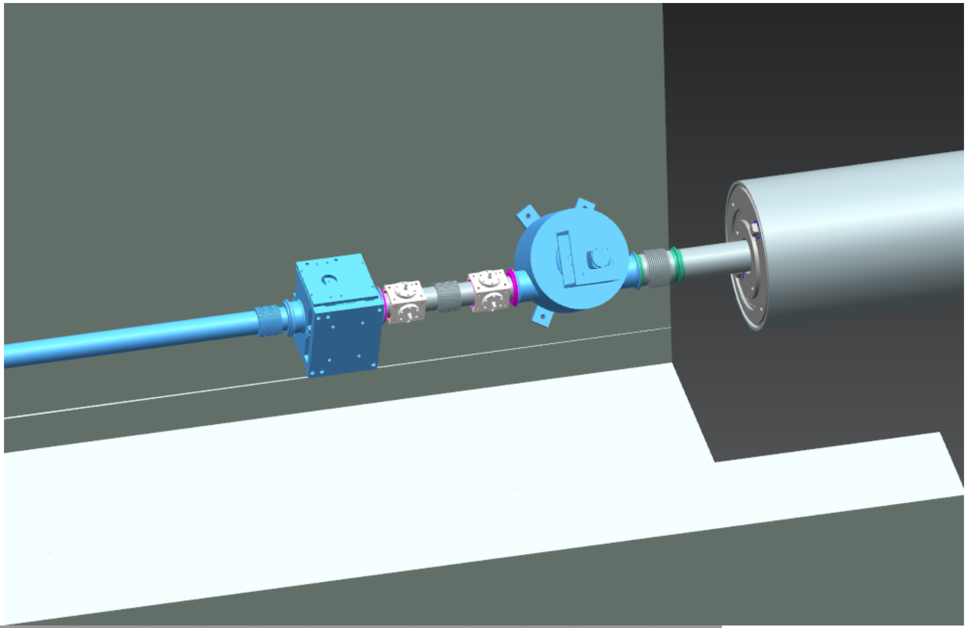
- Yes.
- Beam Scanning requirements are why this window is physically larger than the NuMI / ANU window.
- In addition, provisions for a beryllium catcher screen were added to the beam pipe following the discussion in September
  - Item 5 in assembly F10136776
  - Not explicitly required by FESHM or other source.

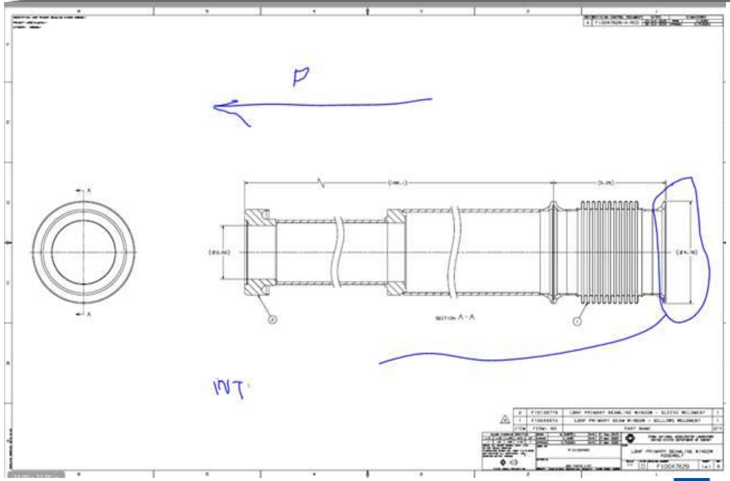
Q4:Does a viable plan exist for replacing the window in accordance with ALARA principles?

- LBNF window will be replaced using a plan very similar to that used in MI-65.
- Beam pipe and window are extracted into the primary beam enclosure and into a shielding cask, allowing worker to be in a relatively benign environment.
- Design of the cask and cask transport equipment occurs later in the project and are not included in this design review.
- LBNF cartridge installation will be similar to the sleeve installation performed at NuMI circa 2003-2004.
- Installing the cartridge and primary beam window occurs in approximately 4 to 5 years (2025) and the procedure for these tasks are not included in this design review.

Q5: Are the interfaces identified and documented appropriately??

- Interfaces to CF and primary beam identified.
- F10128502 is the assembly model file.
- Image on the right show the interfaces between the primary beam window assembly and the primary beam elements.
- Flange at end of F10047628 is the agreed to interface point.



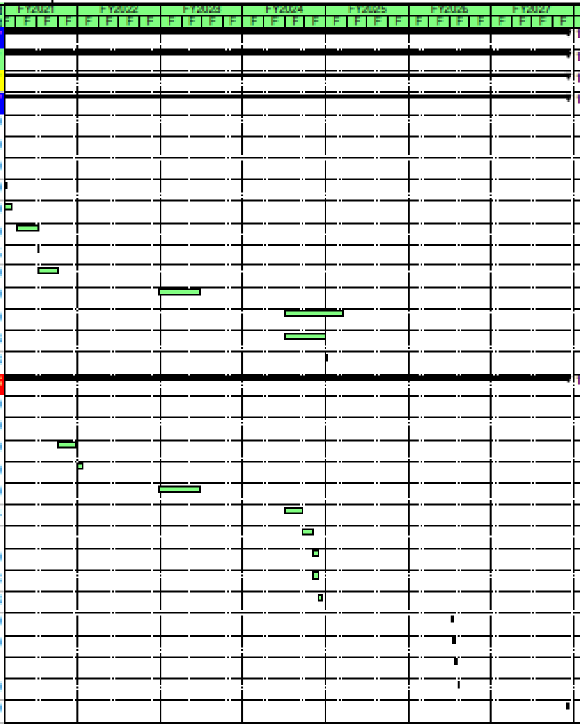


Q6a: Is the final cost and schedule reasonable?
Q6b: Are procurements well planned?

- Excerpt from Schedule shown below and PDF in docdb 20825.
- Note ample float.

Beamline | Beamline - Classic WBS Layout

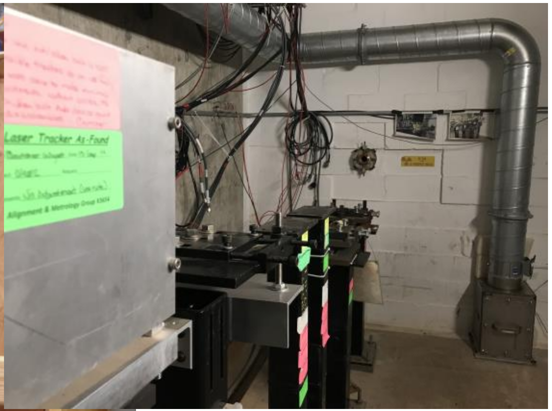
#	Activity ID	Activity Name		Planned Start	Finish	Planned Labor Units	Planned Material Cost
1	131.01.03.03	Beamline	2163d	22-Jan-19 A	10-Sep-27	3137	$188,387
2	131.01.03.03.04	Decay Pipe and Absorber Complex	2163d	22-Jan-19 A	10-Sep-27	3137	$188,387
3	131.01.03.03.04.04	Beam Windows	2163d	22-Jan-19 A	10-Sep-27	3137	$188,387
4	131.01.03.03.04.04.02	Primary Beam Window	2163d	22-Jan-19 A	10-Sep-27	3137	$188,387
5	131133.0302.A14490	1.2MW design for Primary Window	84d	22-Jan-19 A	16-Dec-19 A	160	$0
6	131133.0404.A14500	Analyze and Evaluate active cooling design for Primary Window	35d	02-Jan-20 A	27-Feb-20 A	60	$0
7	131133.0404.A14120	Integrate Window Design into LBNF Beamline	60d	08-May-20 A	27-Oct-20 A	160	$0
8	131133.0404.A14515	Design the window catcher	15d	02-Nov-20	20-Nov-20	112	$0
9	131133.0404.2510	Primary Beam Window Final Design Review	30d	02-Nov-20	15-Dec-20	80	$0
10	131133.0404.A14565	Fabricate the Window Catcher	66d	04-Jan-21*	06-Apr-21	0	$8,000
11	131133.0404.A14540	Window Cask removal fabrication - Deliver	1d	07-Apr-21	07-Apr-21	0	$52,485
12	131133.0404.A14520	Create Drawings for (US Enclosure) primary window	60d	07-Apr-21	30-Jun-21	190	$0
13	131133.0404.2520	Primary Beam Window Requisition and PO development / process	126d	21-Sep-22	24-Mar-23	10	$0
14	131133.0404.A14530	Procurement of primary window and connecting parts	184d	01-Apr-24	19-Dec-24	80	$0
15	131133.0404.A14400	Primary Beam Window - Fabricate & Deliver	126d	01-Apr-24	26-Sep-24	0	$7,483
16	131133.0404.A14140	Primary Beam Window Assembly and Test (window, beam pipe, shielding, instrumentation, cooling)	10d	27-Sep-24	10-Oct-24	185	$3,513
17	131.01.03.03.04.04.02.01	Primary Window Support	1892d	21-Feb-20 A	10-Sep-27	2100	$116,906
18	131133.0404.A14210	Create Design for Primary Beampipe Cartridge with Transport System for Replaceable Window Design	55d	21-Feb-20 A	24-Aug-20 A	330	$0
19	131133.0404.A14220	Create Drawings for Primary Beampipe Cartridge with Transport System	45d	25-Aug-20 A	27-Oct-20 A	120	$0
20	131133.0404.A14250	Update & Finalize Design for Primary Beampipe Cartridge with Transport Syst & Integrate into Replaceable Window Design	60d	01-Jul-21	24-Sep-21	312	$0
21	131133.0404.A14280	Integrate Replacement Window Final Design into LBNF Beamline Layout & Update Replacement Window Support Structure (and A	20d	27-Sep-21	22-Oct-21	176	$0
22	131133.0404.A29695	Primary Beampipe Cartridge Requisition and PO development / process	126d	21-Sep-22	24-Mar-23	10	$0
23	131133.0404.A14230	Fabricate Primary Beampipe Cartridge with Transport System	60d	01-Apr-24	24-Jun-24	226	$46,864
24	131133.0404.A14240	Assemble & Test Primary Beampipe Cartridge with Transport Syst	30d	25-Jun-24	06-Aug-24	228	$8,331
25	131133.0404.A14260	Fab any Parts needed from changes to Primary Beampipe Cartridge Sys Design and Steel Shielding for Cartridge - Labor	15d	07-Aug-24	27-Aug-24	304	$0
26	131133.0404.A14270	Fab any Parts needed from changes to Primary Beampipe Cartridge Sys Design and Steel Shielding for Cartridge - M&S	15d	07-Aug-24	27-Aug-24	0	$44,876
27	131133.0404.A14300	Assembly of Primary Beampipe Cartridge System	10d	28-Aug-24	11-Sep-24	114	$1,213
28	131133.0404.A14310	Fudicialize and Map of Embedded Primary Beampipe Liner	5d	09-Apr-26	15-Apr-26	42	$0
29	131133.0404.A14320	Pre-alignment Primary Beampipe within Cartridge Relative to Mapped Liner	5d	16-Apr-26	22-Apr-26	42	$0
30	131133.0404.A14330	Installation of Primary Beampipe Cartridge System	10d	23-Apr-26	06-May-26	94	$15,621
31	131133.0404.A14340	Final Alignment (Confirmation) of Primary Beampipe Cartridge within Enclosure	5d	07-May-26	13-May-26	42	$0
32	131133.0404.A14370	Final Alignment of Proton Beam Window	5d	03-Sep-27	10-Sep-27	60	$0



Fermilab

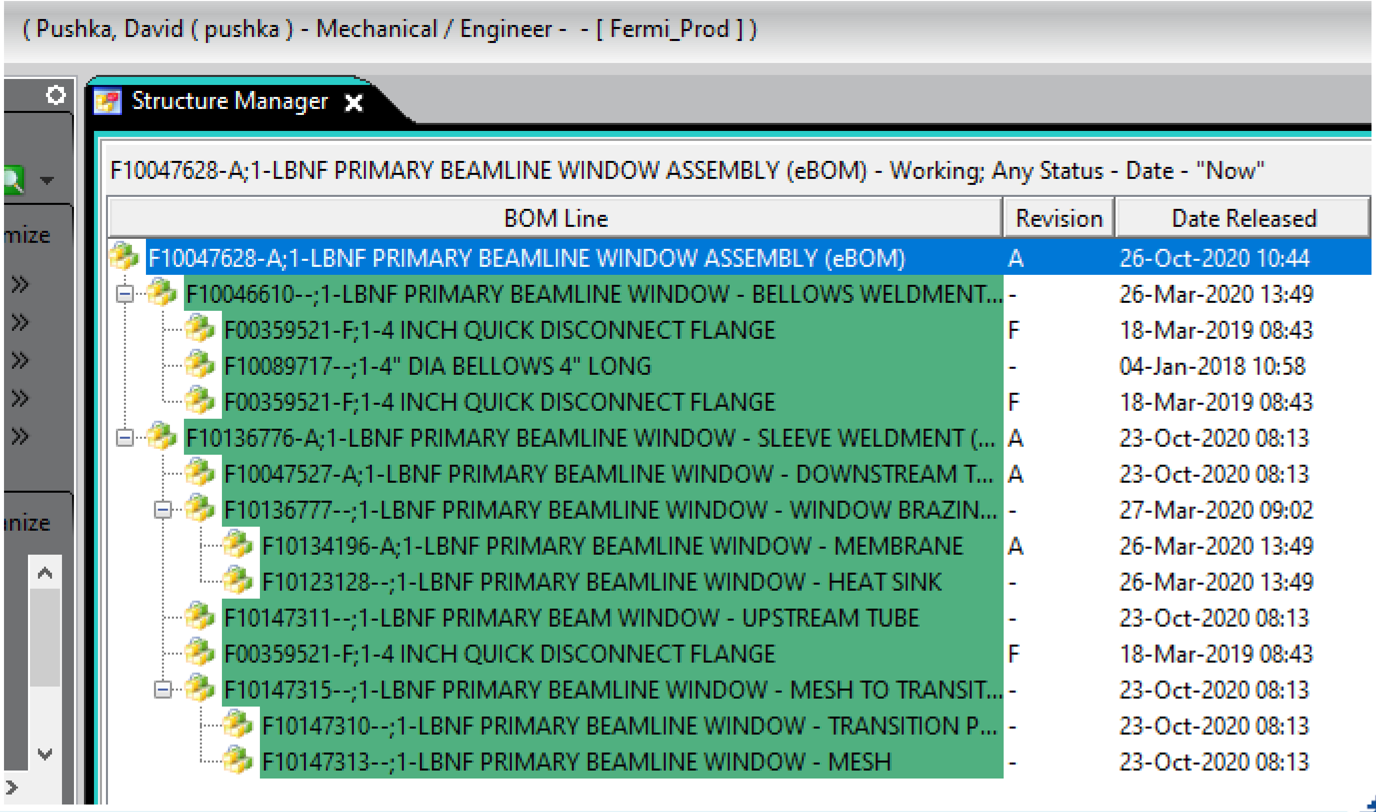
Q7a: Is the installation thought out and planned for?
Q7b: Potential problems identified?

- Yes, the installation has been thought out and planned for
  - The plan mirrors plans previously successfully used in MI-65
  - Generous provisions provided for cartridge installation grouting will accommodate greater than expected CF placement errors.
- IMPACT tool use will be required prior to performing this work many, many months from now.
  - Potential problems are considered again using this tool.
  - HA for NuMI window change at https://ad.fnal.gov/cgi-bin/admin/haForm.pl?haID=1590 is a starting point.



Q8: Are the documents (requirements, specifications, schematics, engineering notes, procedures, and drawings) at the appropriate level for a final design?

- Drawing are released in TC
- Stand Alone Specifications are not needed (key specification are embedded in the drawings & QA plan.)



The end

Back-up material on a Beryllium Catcher:

- A “beryllium catcher” is a second window, located on the beam line side of a primary beam exit window, designed to limit the propagation of beryllium chards into the beamline in the event of a failure of a beryllium window.
- There is no requirement for a beryllium catcher in FESHM.
- One was installed in NuMI because it was thought to be a good idea.
  - A beryllium primary beam exit window failed in the MI abort when someone poked at it with a tool.
  - Very thin beryllium windows in a vacuum vessel in MTA were exposed to high differential (well above the design) when the vessel was pressurized causing a titanium window to fail. This is a very different situation from a primary beam exit window.
- A catcher window sees beam heating, but has little effective cooling (it is in a vacuum).
- The NuMI catcher has openings around the perimeter to allow the downstream vacuum to be evacuated.
- The LBNF design includes provision for a screen to serve as a catcher, while allowing more effective conductance for evacuation.
- The laboratory requirements for a catcher need to be better defined and the pros and cons associated with a catcher need to be investigated and documented.