LBNF Hadron Absorber: Mechanical Design

Preliminary Design Review

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Fermilab CERN Sanford Underground Research Facility U.S. DEPARTMENT OF ENERGY Office of Science

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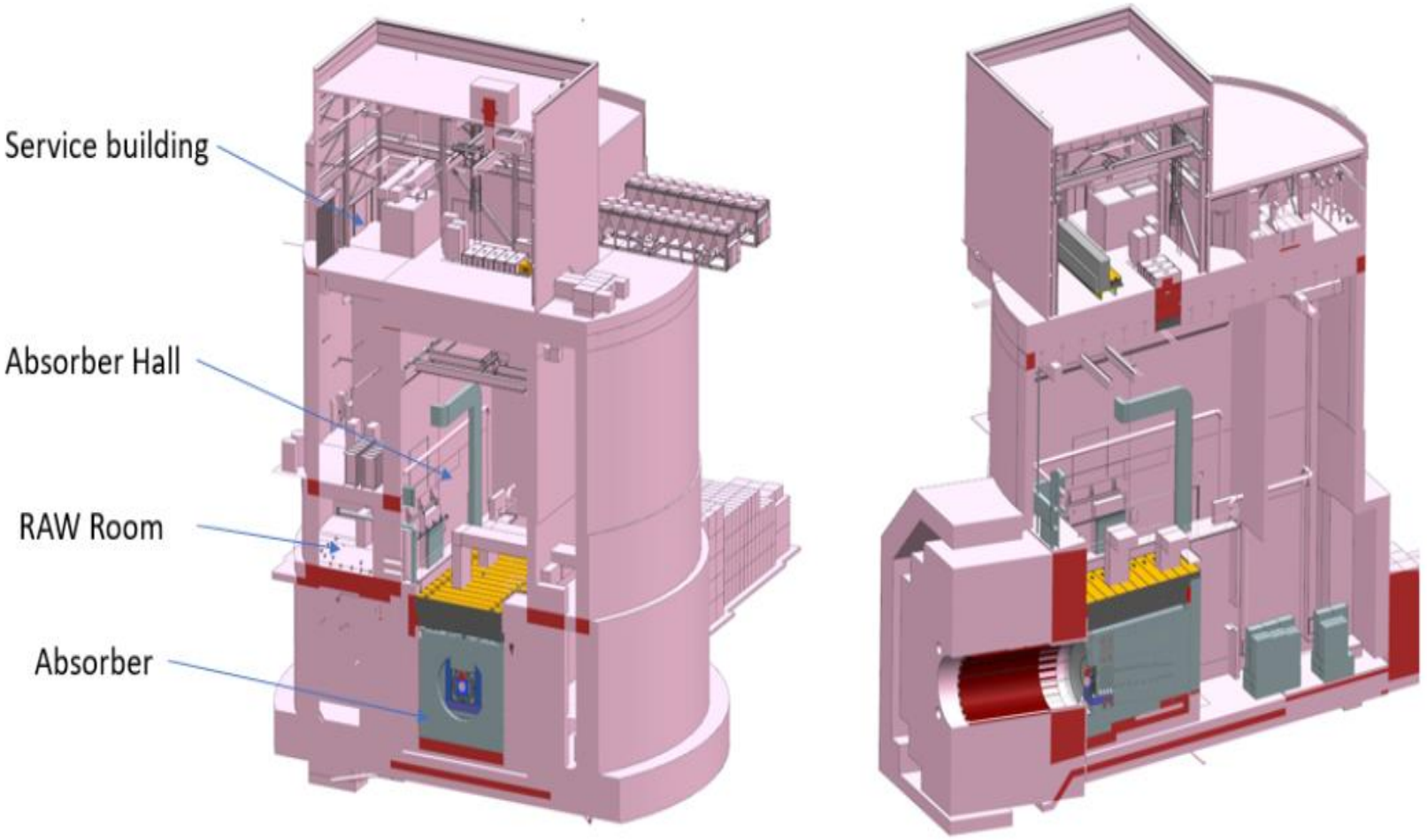
Hadron Absorber Complex



Introduction: Hadron Absorber

- The configuration of the Absorber is determined through an iterative process between the engineering design, radiological safety, MARS modeling, and the beamline groups.

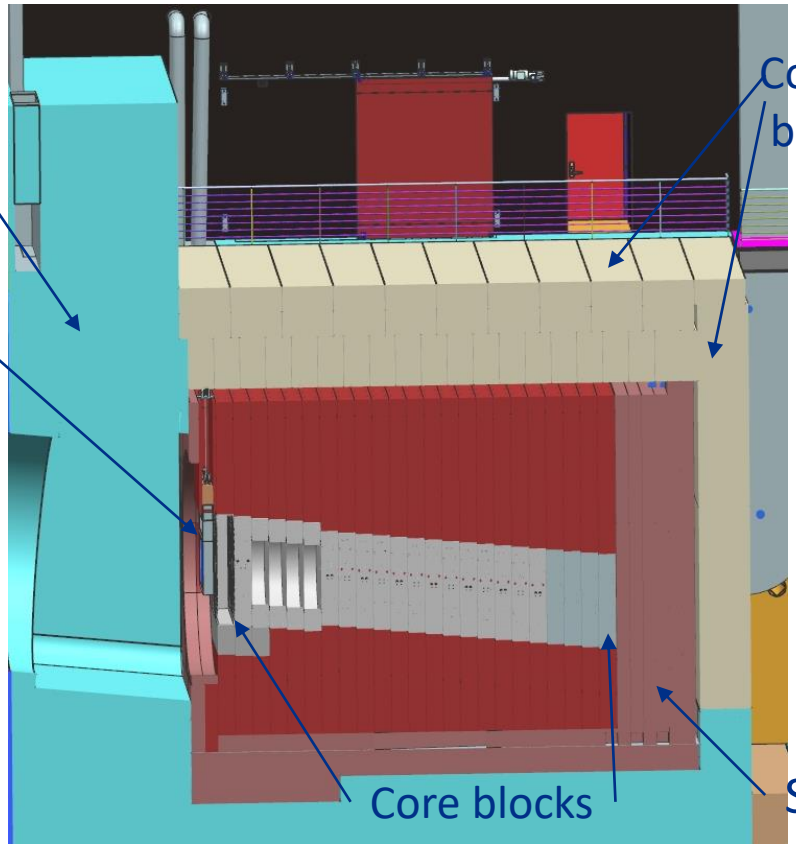
- Designed for the optimized beam condition (Dune-doc-294):

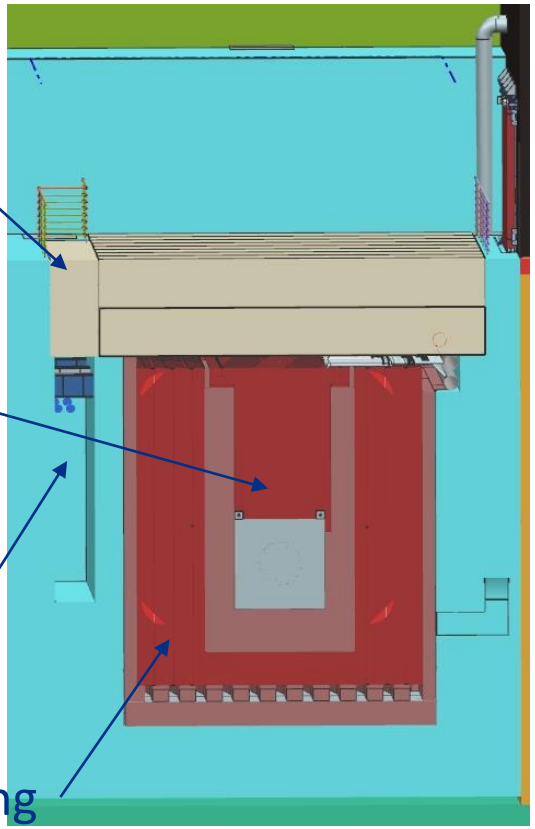
Proton beam energy (Gev)	Protons per cycle	Cycle time (Sec)	Beam power (MW)
120	1.5E+14	1.2	2.40

- Energy deposition in the Absorber and radiological parameters are determined by MARS. They are a function of the type of Target used in the Target Hall.

LBNF Absorber Mechanical Design

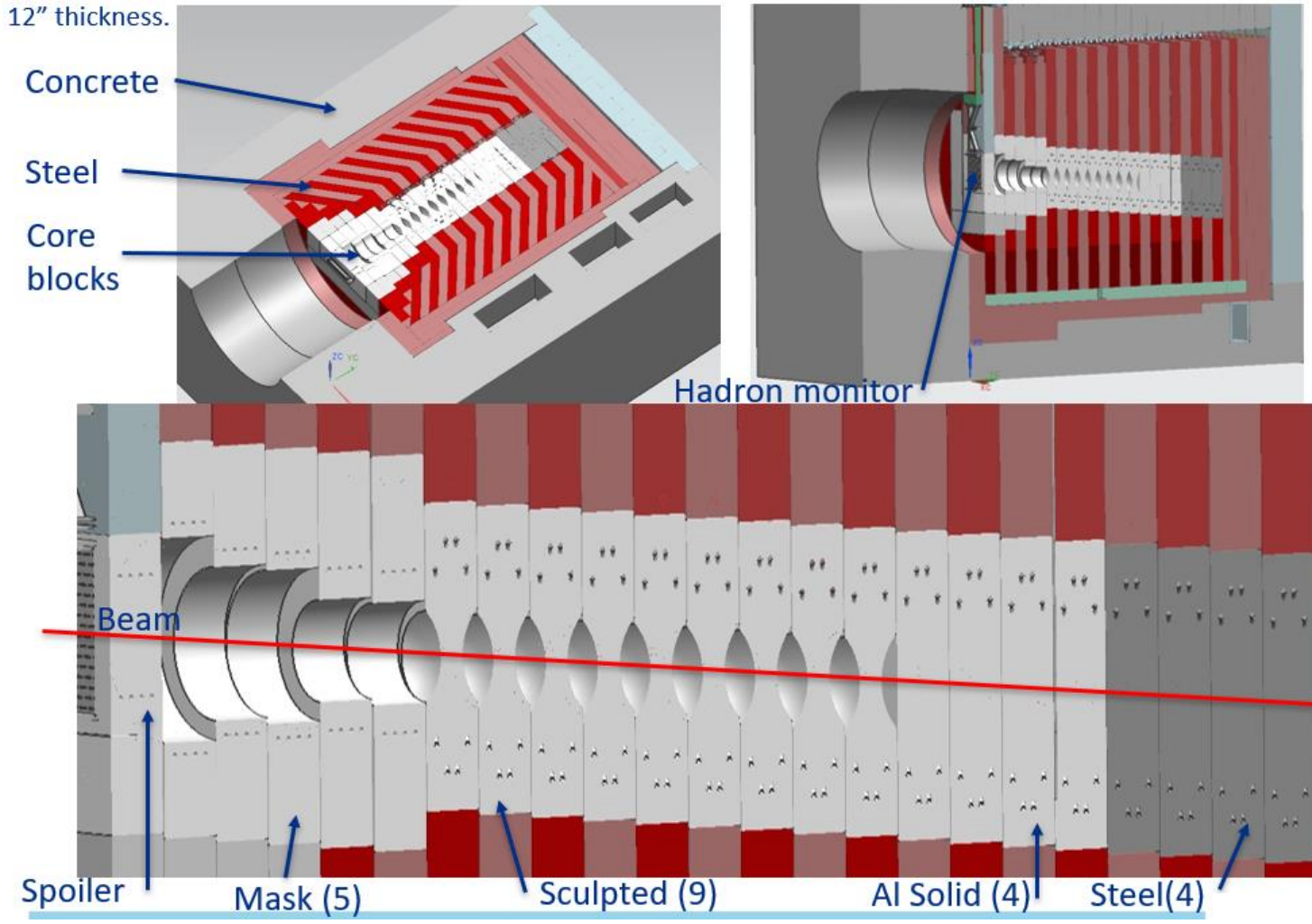
The Long-Baseline Neutrino Facility (LBNF) Hadron Absorber is located downstream of the decay pipe. It consists of actively cooled aluminum and steel blocks surrounded by steel and concrete shielding. The absorber provides radiation protection to personnel and keeps soil and ground activation levels below allowable limits. It is designed for 2.4 MW beam operations. The total heat load deposited into the absorber is approximately 700 kW with 1.00 meter NUMI target, 477kW with 1.50 meter RAL target, 400kW with 2.00 meter NUMI target.





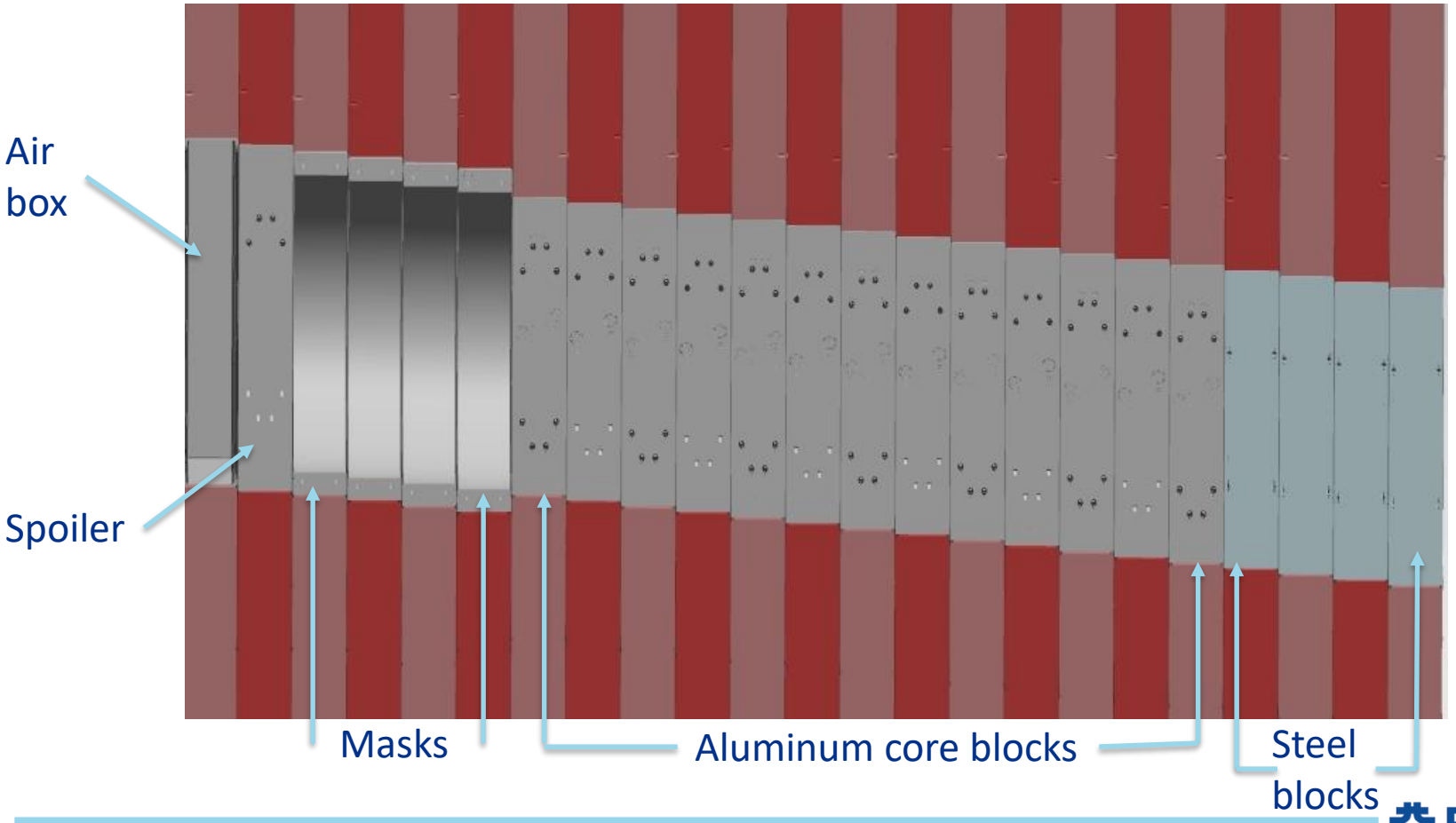
LBNF Absorber (Previous Design)

The absorber core includes: Aluminum Spoiler, five Aluminum Mask blocks with different holes diameter, nine sculpted Aluminum blocks, four full Aluminum blocks and four Steel blocks. Spoiler dimensions: 40”W ;40”H;12” thickness. Mask core blocks dimensions: 77”/79W; 77”H; 12” thickness . Sculpted Al, Full Al, Steel blocks dimensions: 60”/62W; 60”H; 12” thickness.



LBNF Absorber Core (Current Design)

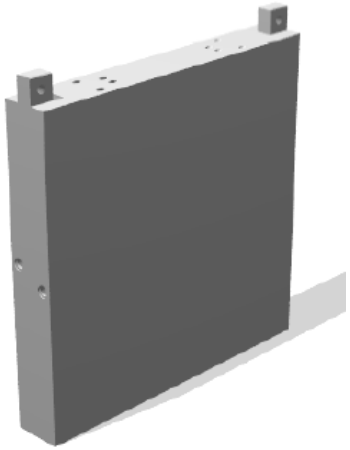
The water cooled absorber core is the major part of the absorber.
The absorber core includes: The Aluminum Spoiler, four Aluminum Masks, thirteen Aluminum blocks and four Steel blocks. Five millimeters gap between two neighbor core blocks is made during installation.
Core blocks dimensions: Spoiler 79”Wx 77”H x12”Th.; Mask: 77”/79Wx77”Hx12”Th. Aluminum and Steel blocks 67”/69W; 67”H; 12”Th.



Absorber core

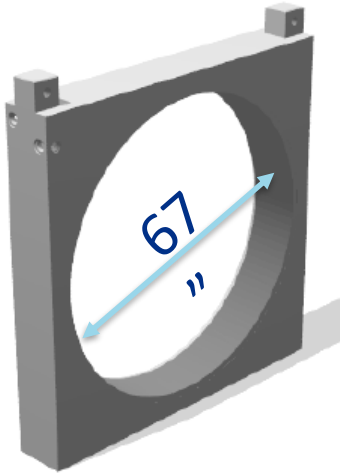
Absorber core is water cooled. All Aluminum blocks have gun-drilled cooling lines:

Spoiler



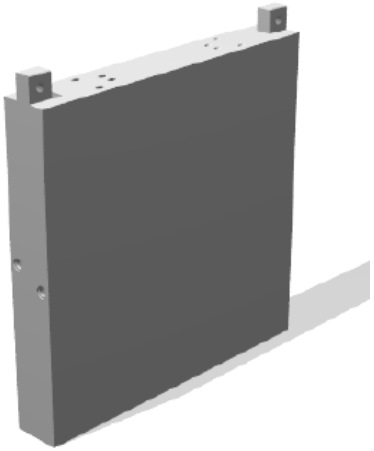
- Material: 6061-T6 Aluminum
- Quantity: 1
- Dimensions: 79”W X 77”H X 12”
- Cooling lines: 4
- Weight: 7150 lb

Mask



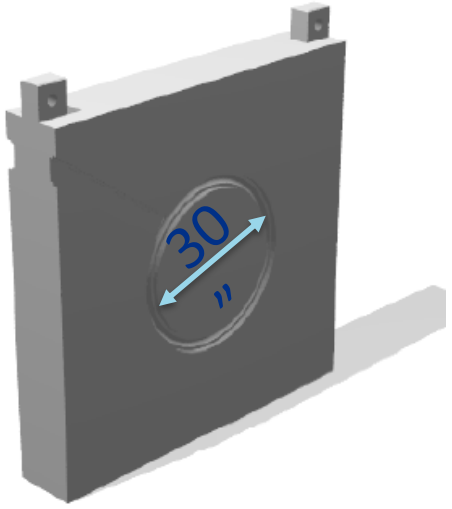
- Material: 6061-T6 Aluminum
- Quantity: 4
- Dimensions: 77”-79”W X 77”H X 12”
- Cooling lines: 2
- Weight: 2800 lb

Al core



- Material: 6061-T6 Aluminum
- Quantity: 13
- Dimensions: 67”-69”W X 67”H X 12”
- Cooling lines: 4
- Weight: 5180 lb

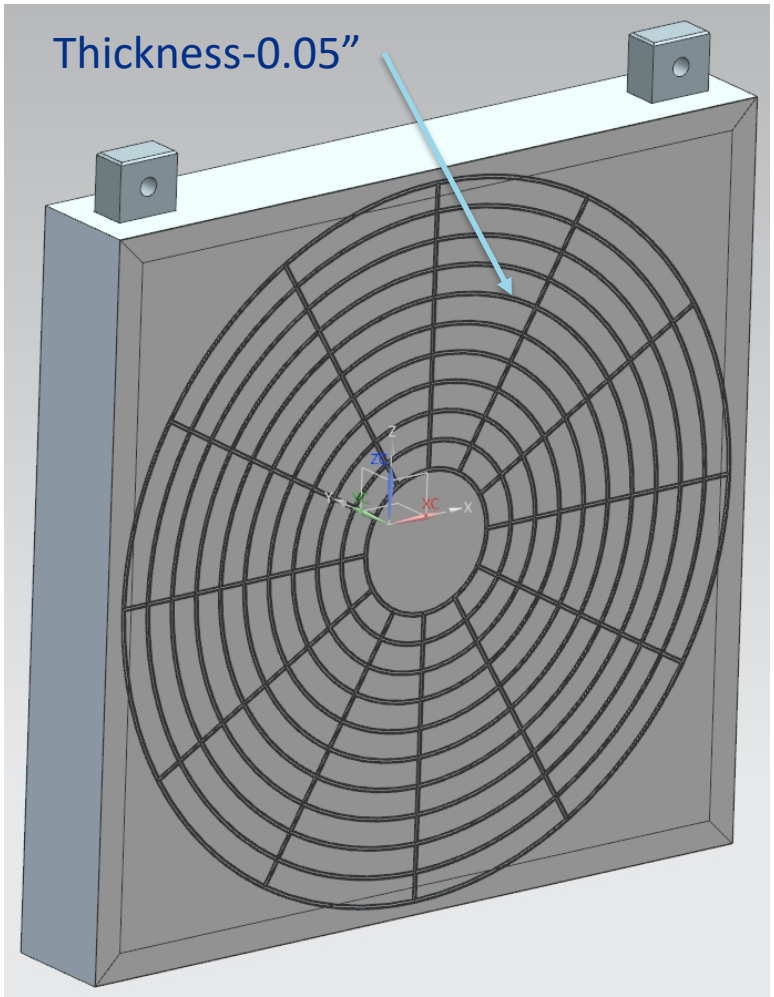
Steel core

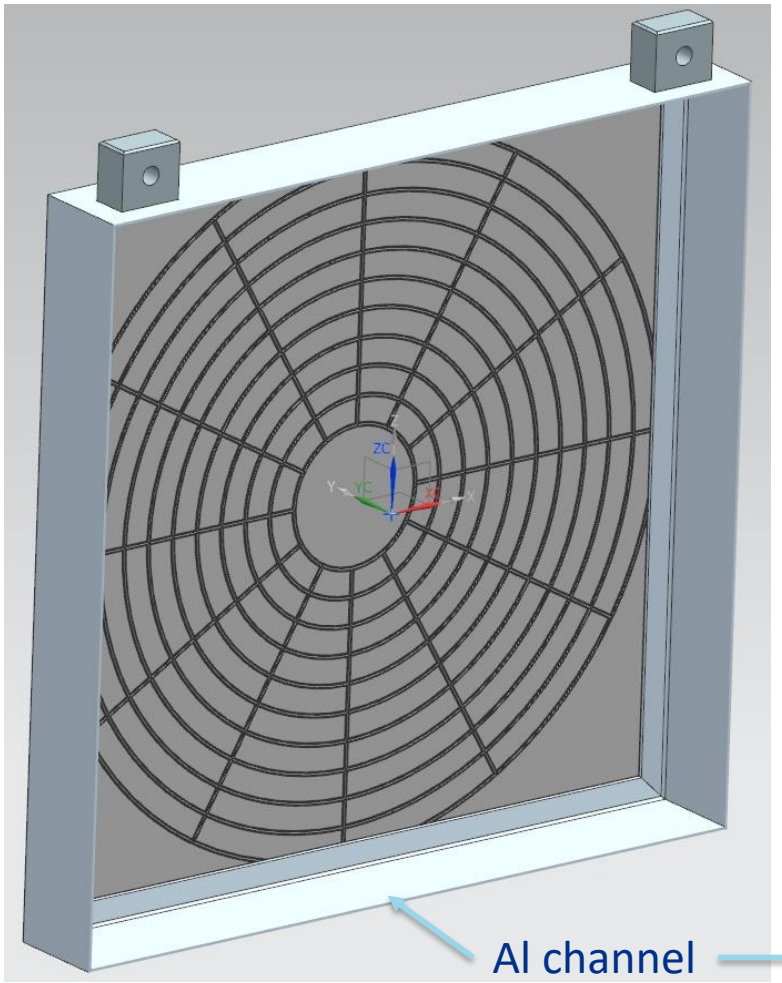


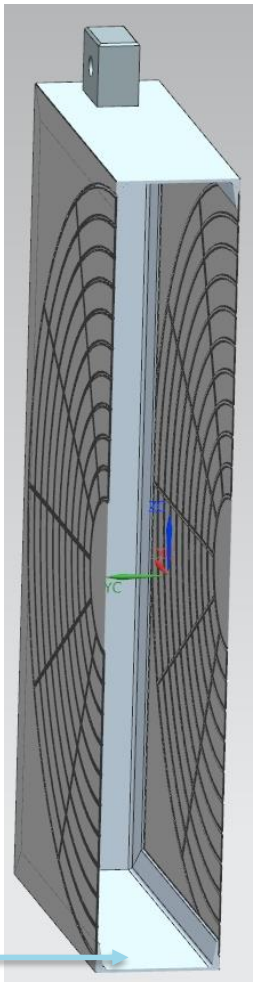
- Material: A36 steel
- Quantity: 4
- Dimensions: 67”-69”W X 67”H X 12”
- Cooling lines: 2. No gun-drilled internal channels
- Weight: 15,550 lb

Air box

The air box is designed to keep most of the radioactive air inside the box. It has air pressure equalization holes. The air box is located in the front of the absorber core blocks. Air box dimensions: 77”Wx77”Hx12”





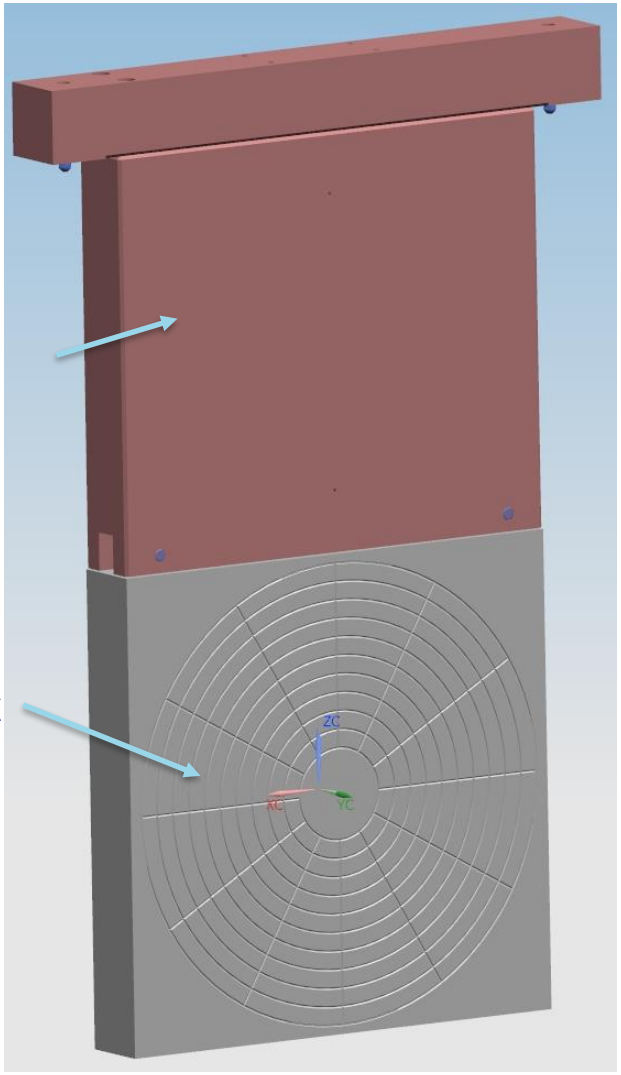


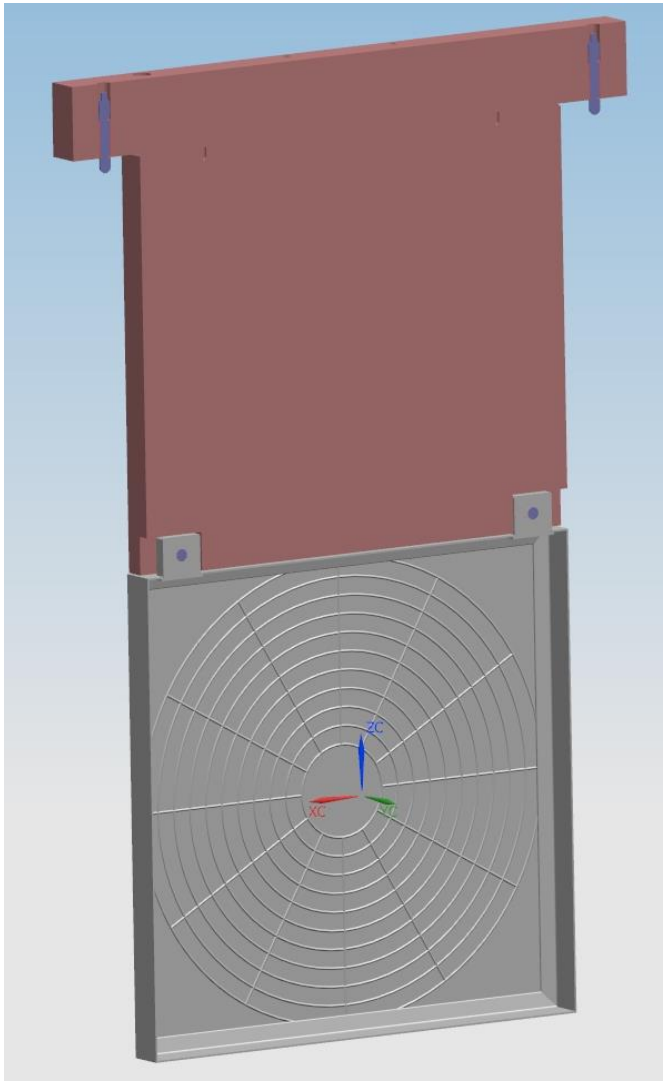
Air box module assembly

The air box is attached to the steel module. The air box can be easy replaced with a core block.

Module

Air box

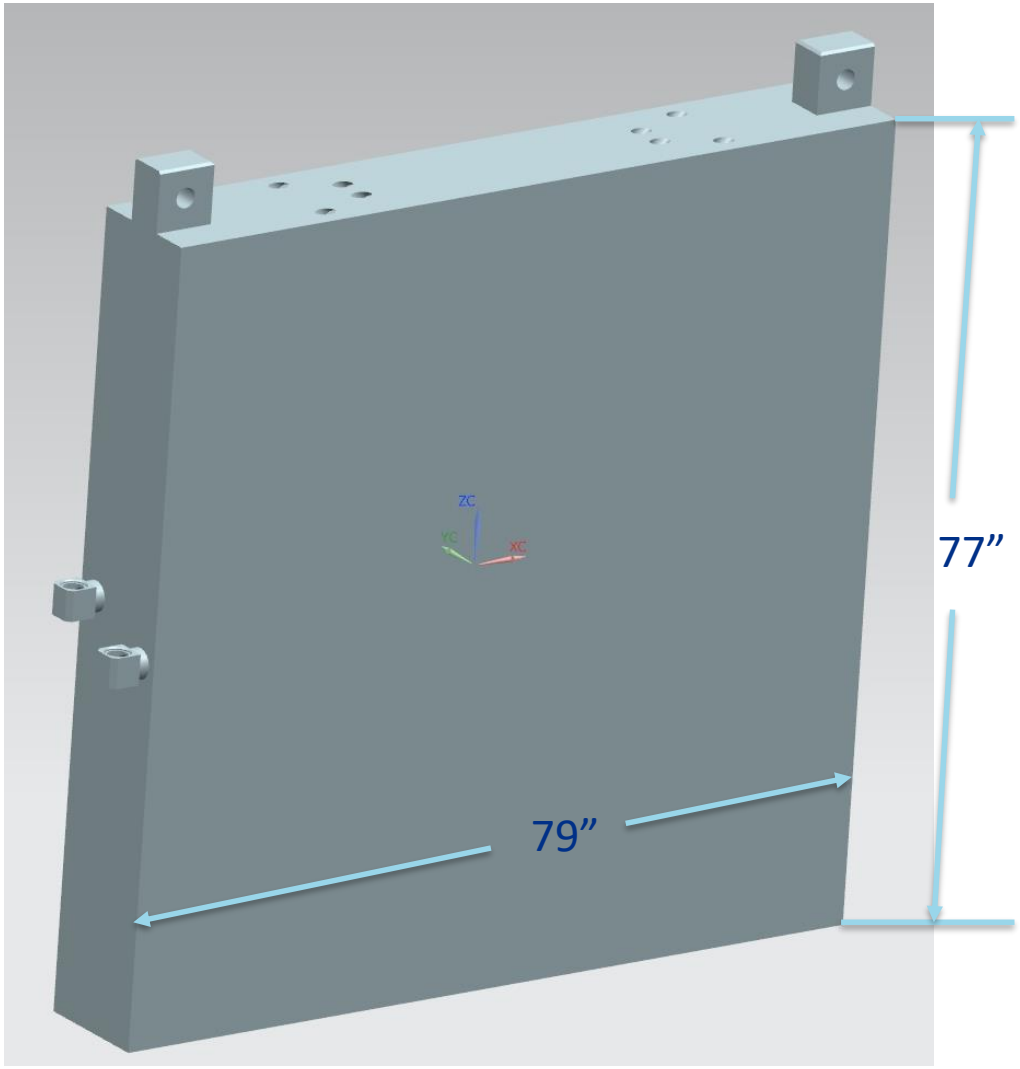


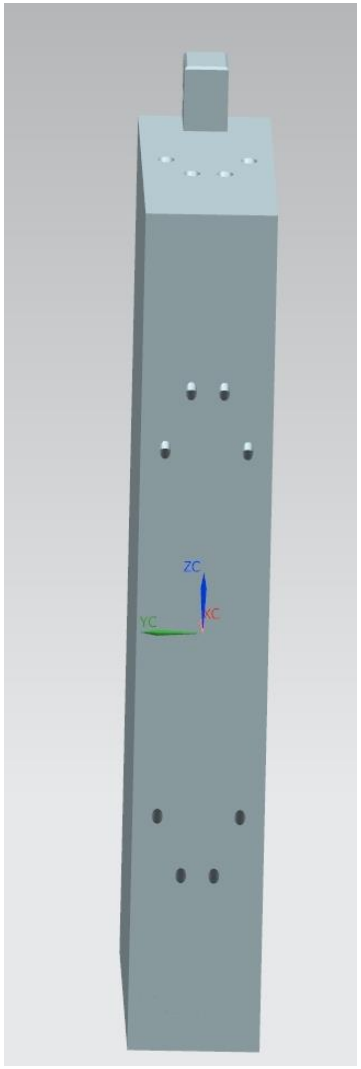


Fermilab

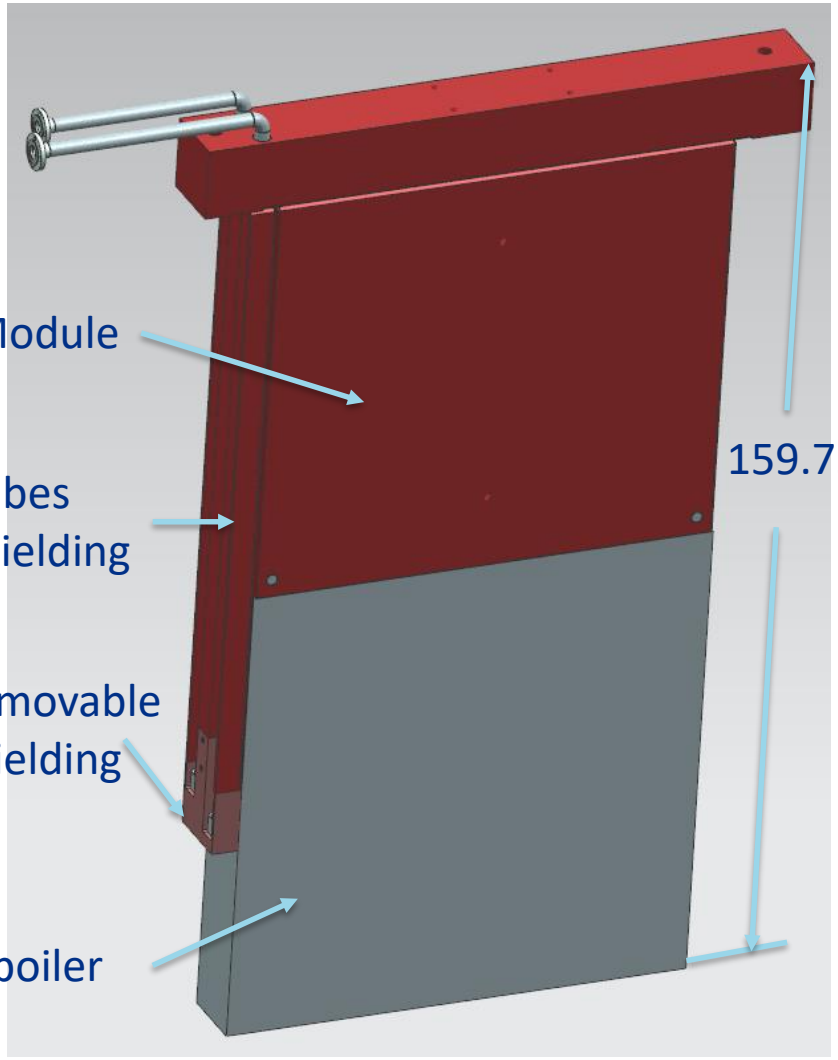
Spoiler

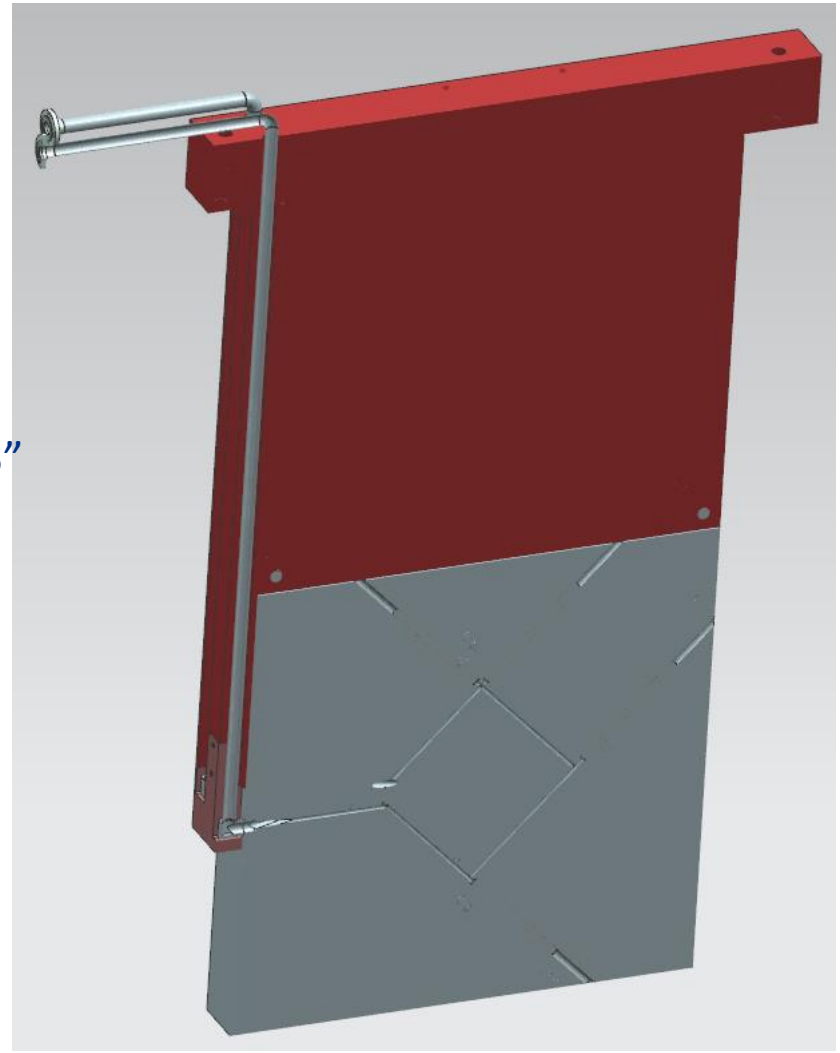
The spoiler size 79”x77”x12” and the same design as the core blocks.





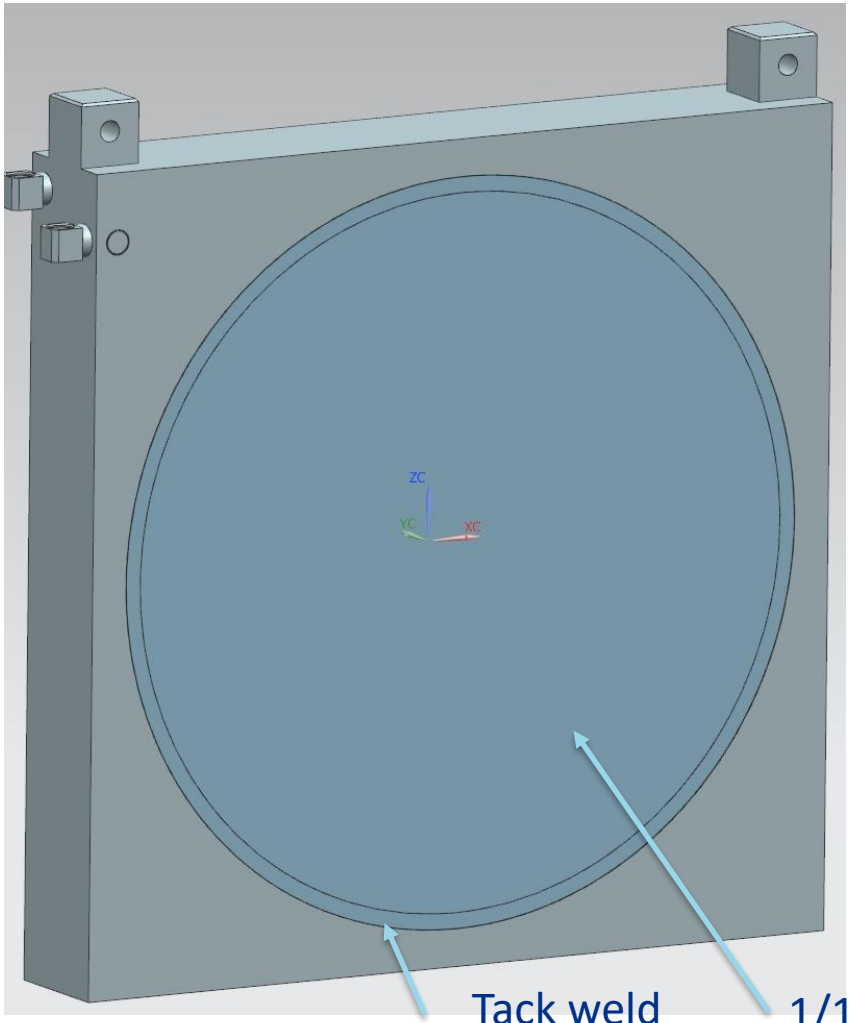
Absorber spoiler module assembly

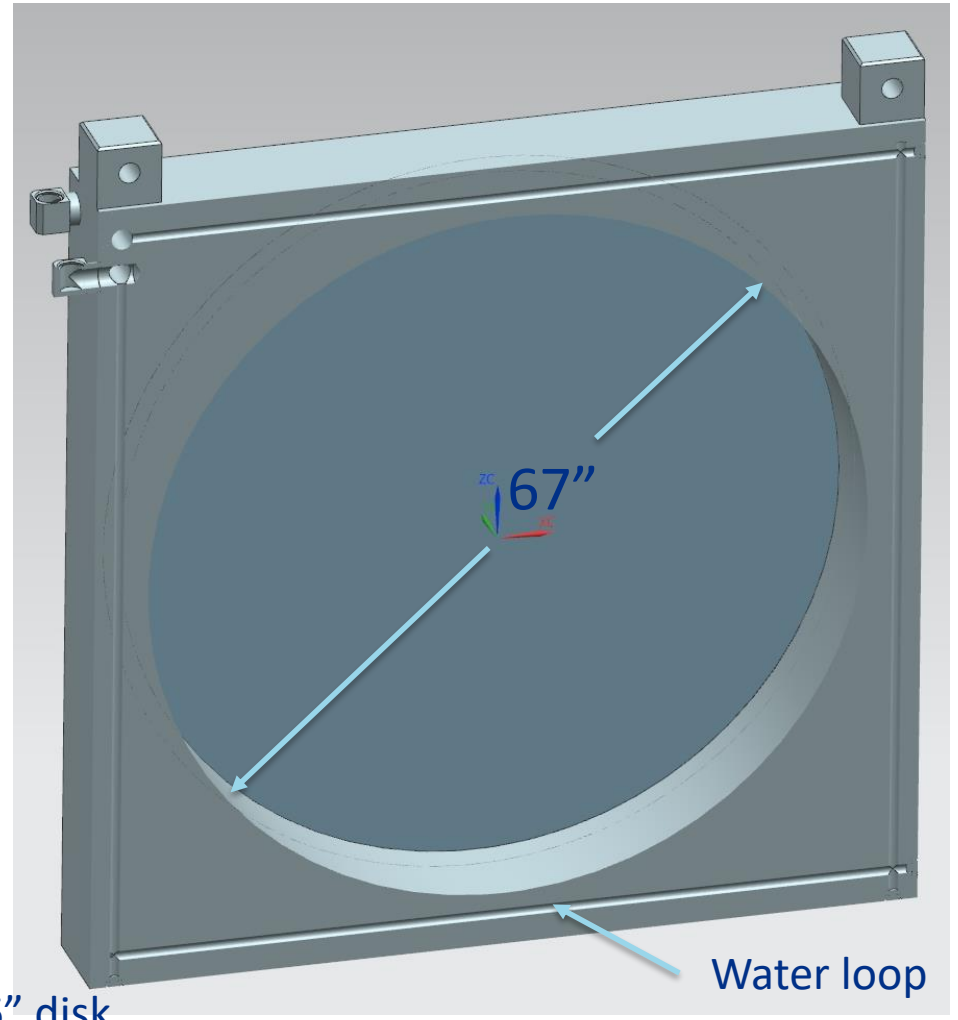




Mask block

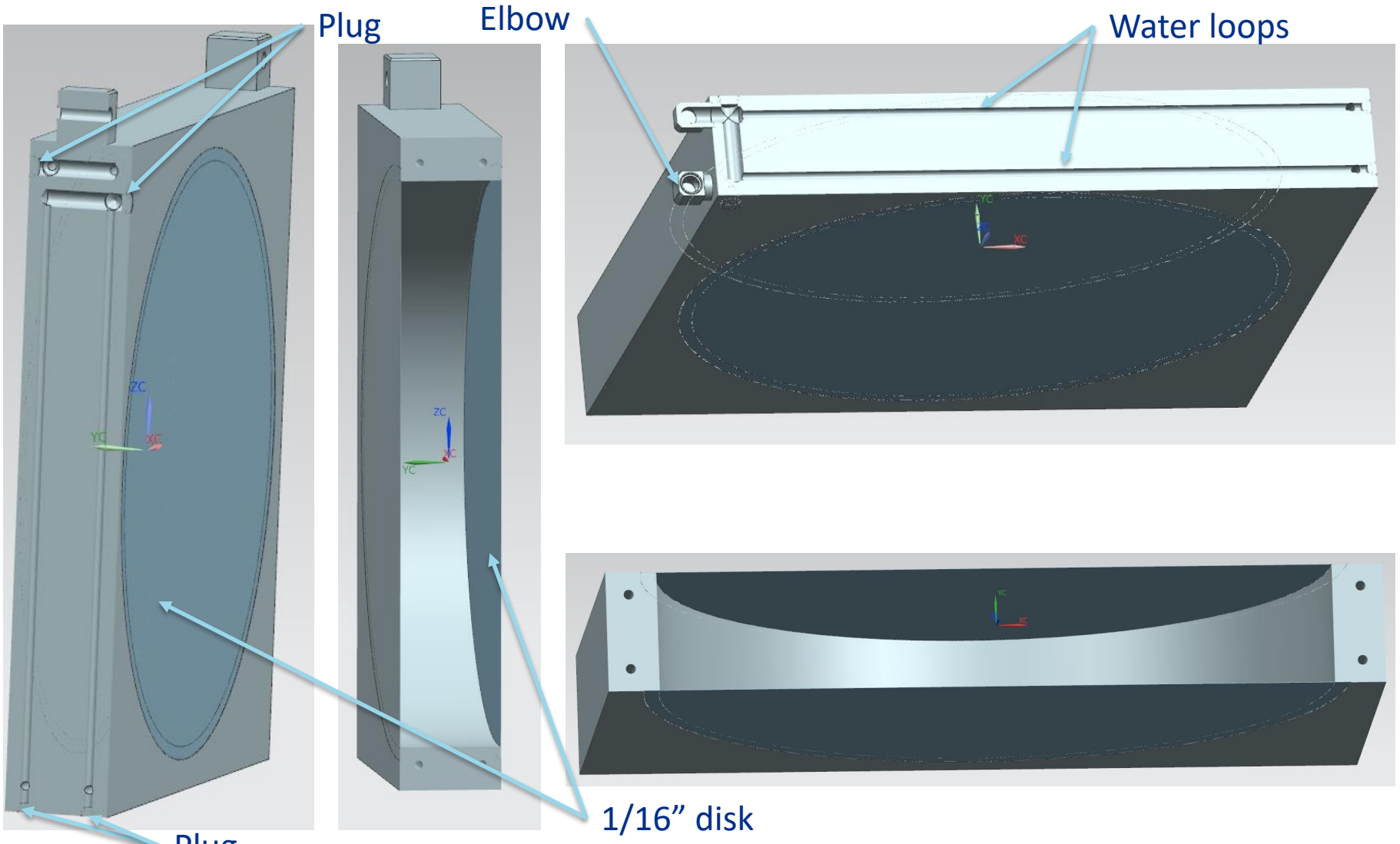
The mask blocks are made from aluminum, dimensions 77”-79”Wx77”Hx12”.
The hole 67” diameter is located on the center of the block. The hole is covered with two thin 1/16”disks to keep the radioactive air inside the mask.



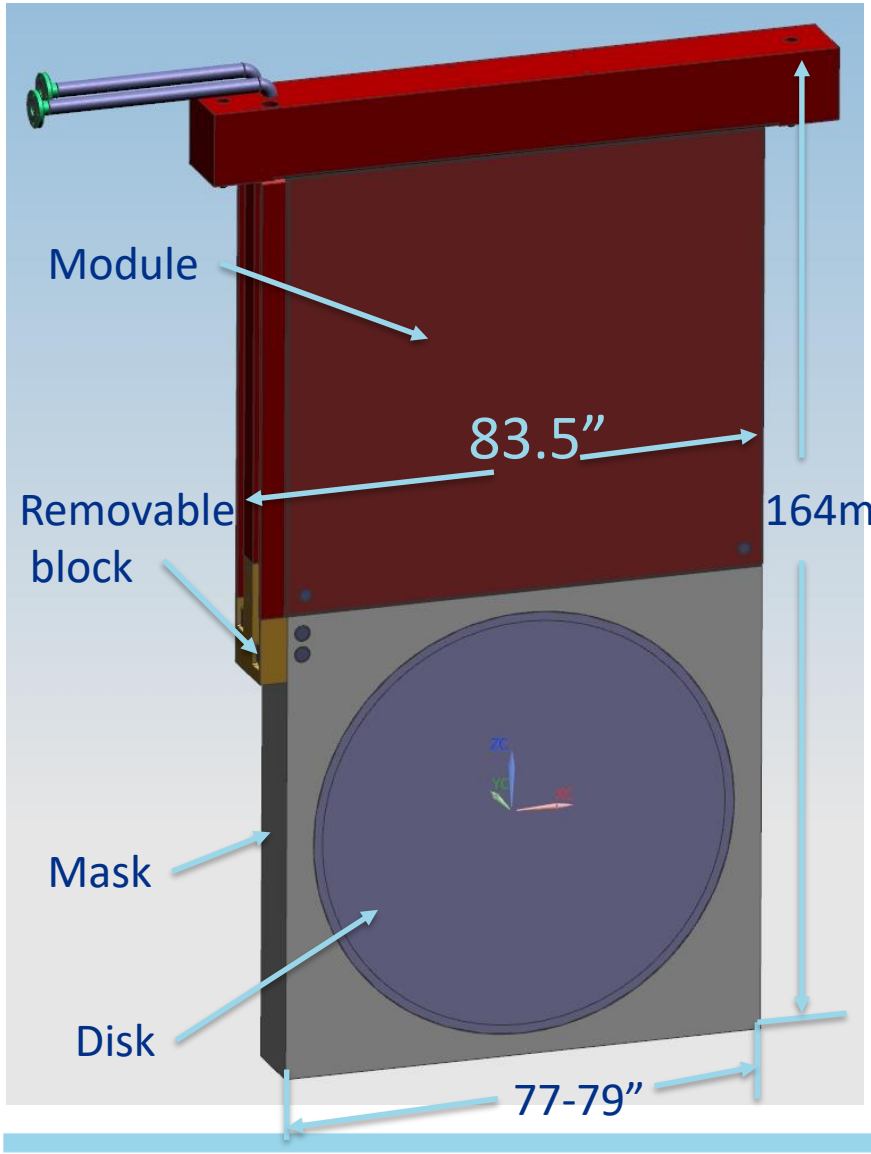


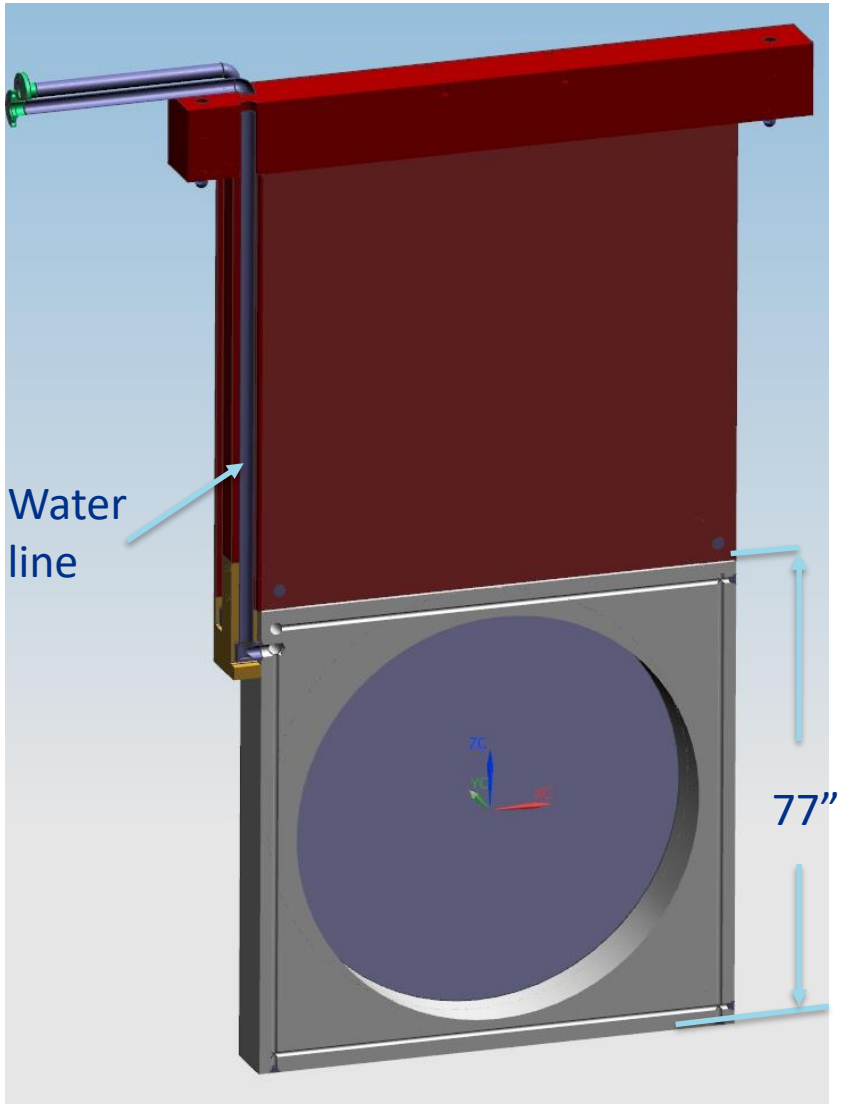
Mask block cross-section

Two water loops are drilled in the mask block.



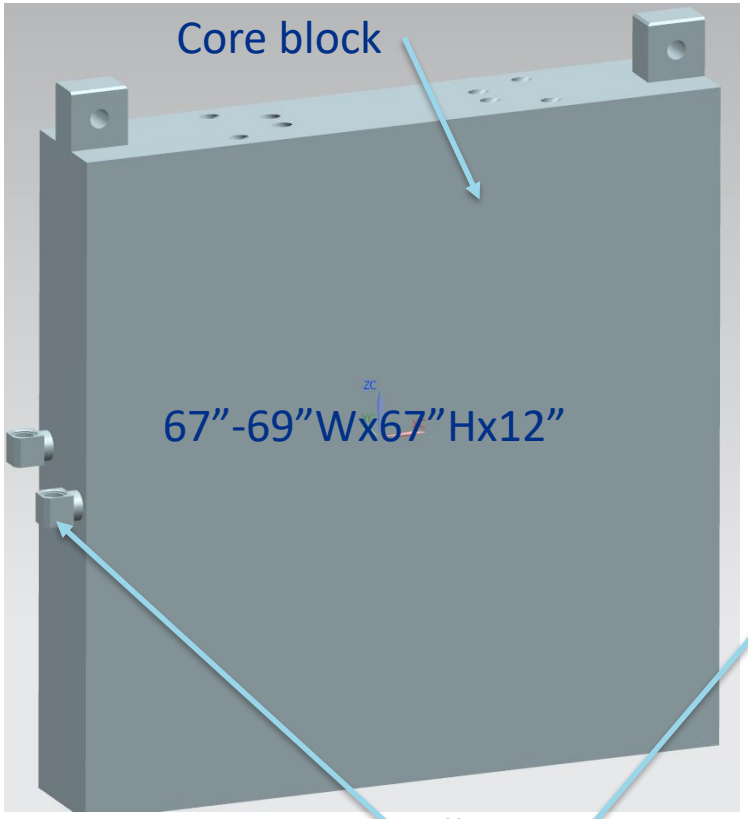
Absorber mask-module assembly

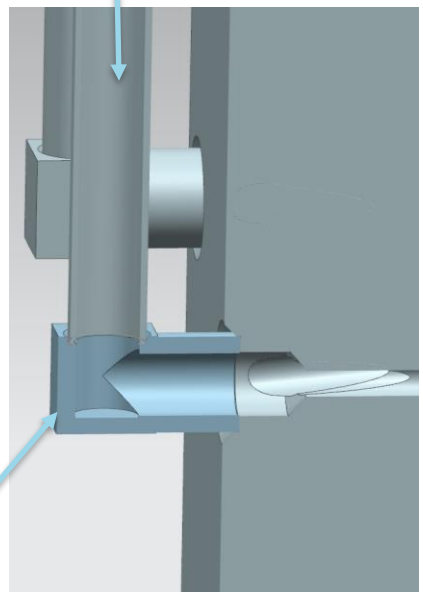


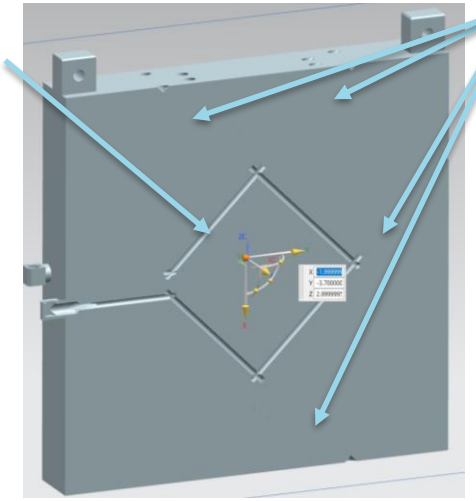


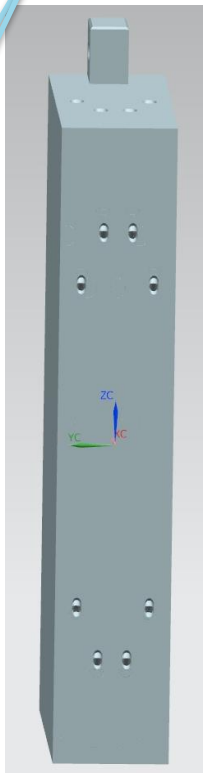
Aluminum core block

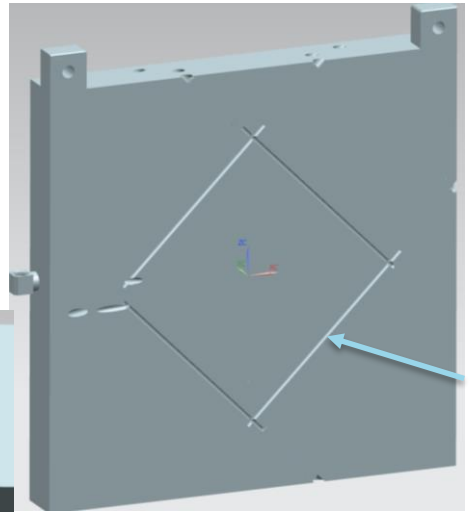
The four water lines are drilled in the absorber aluminum core block and plugged by Al rods creating water loops. Three holes are drilled through the inlet and outlet ports for loops connection. Two elbows are welded to the block ports and connected to the manifold with pipes.

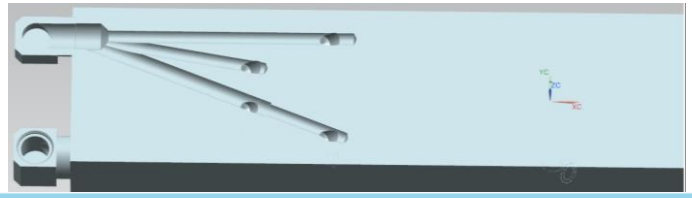


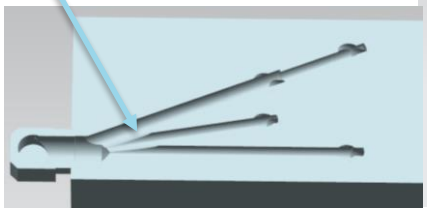




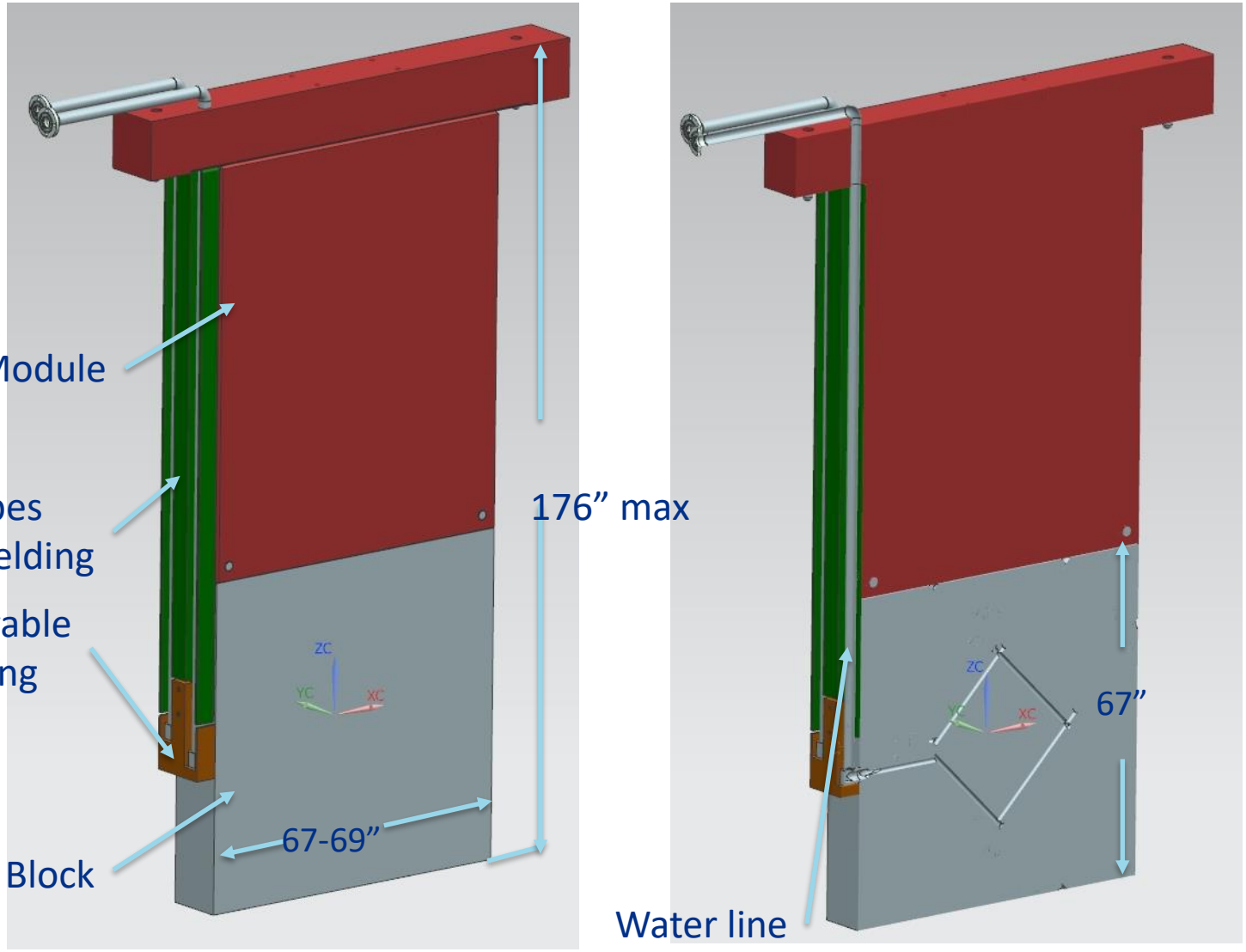






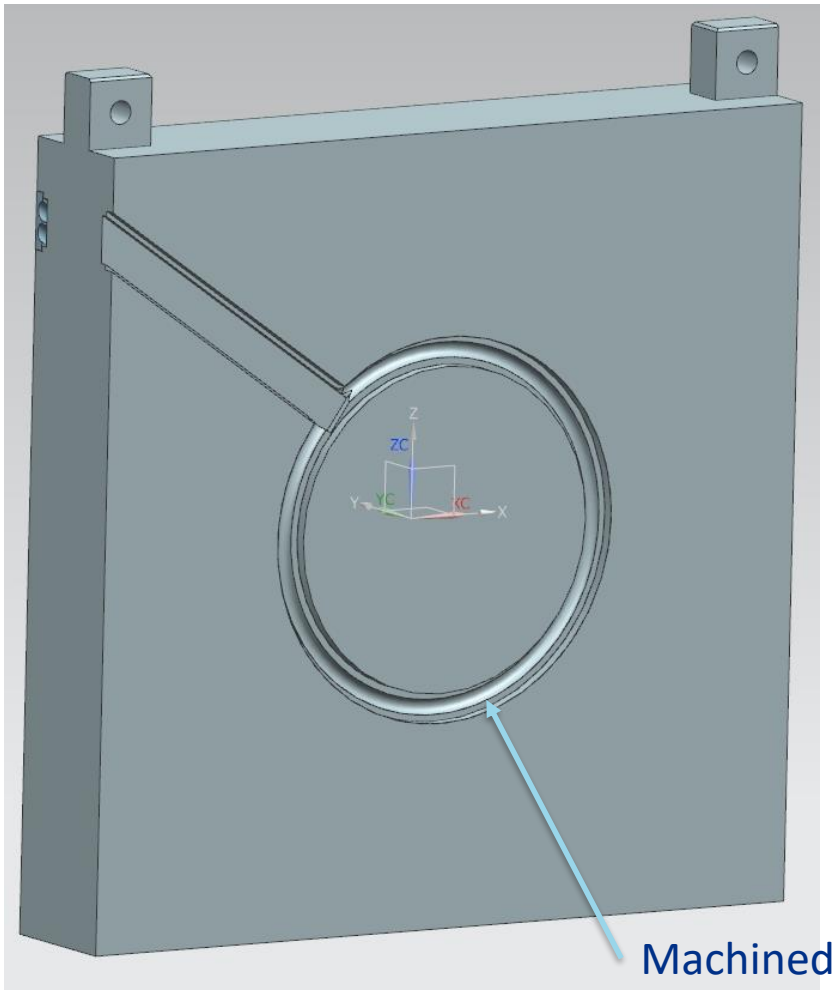


Absorber Al core block –module assembly



Steel core block

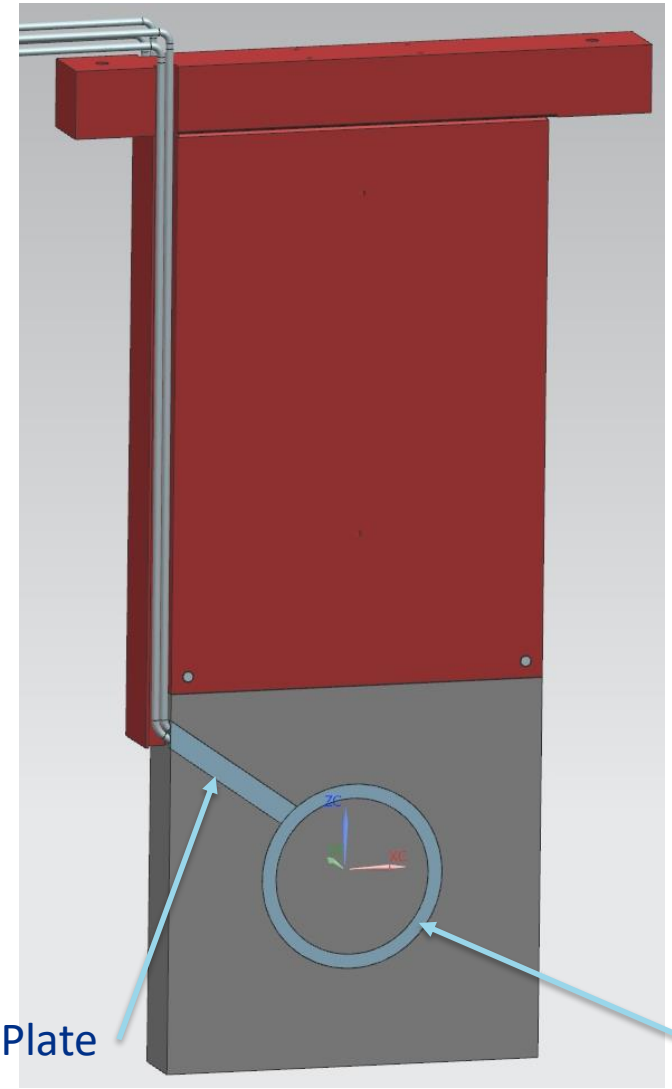
The steel core block has the same size as Al core block, 67”-69”W X 67”H X 12” ”. Groves on both sides of the block are machined for the water cooling tubes.

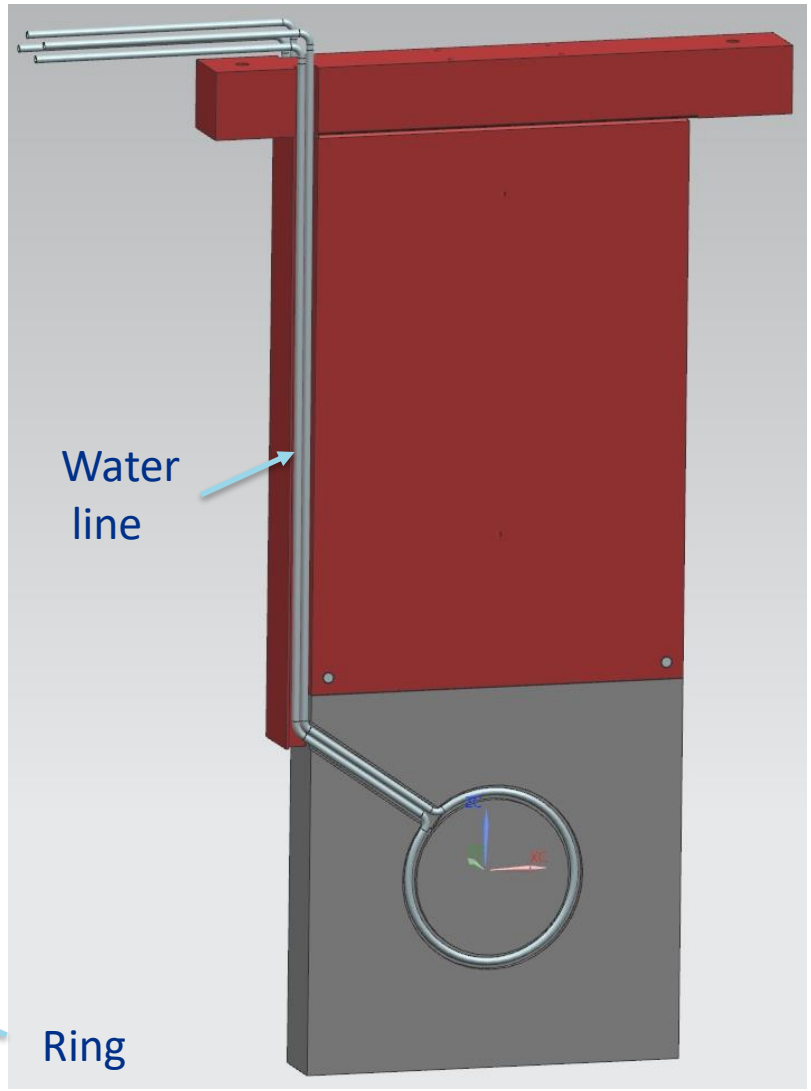


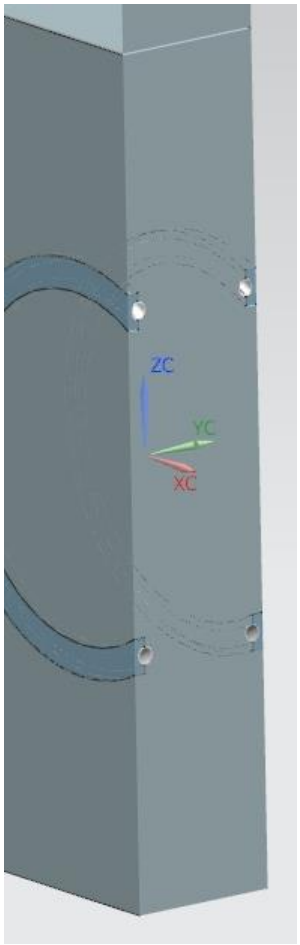
Machined grove

Steel core block module assembly

The water line is banded and welded from 1” pipe. The water line is covered and pressed to the block by ring and holding plate.

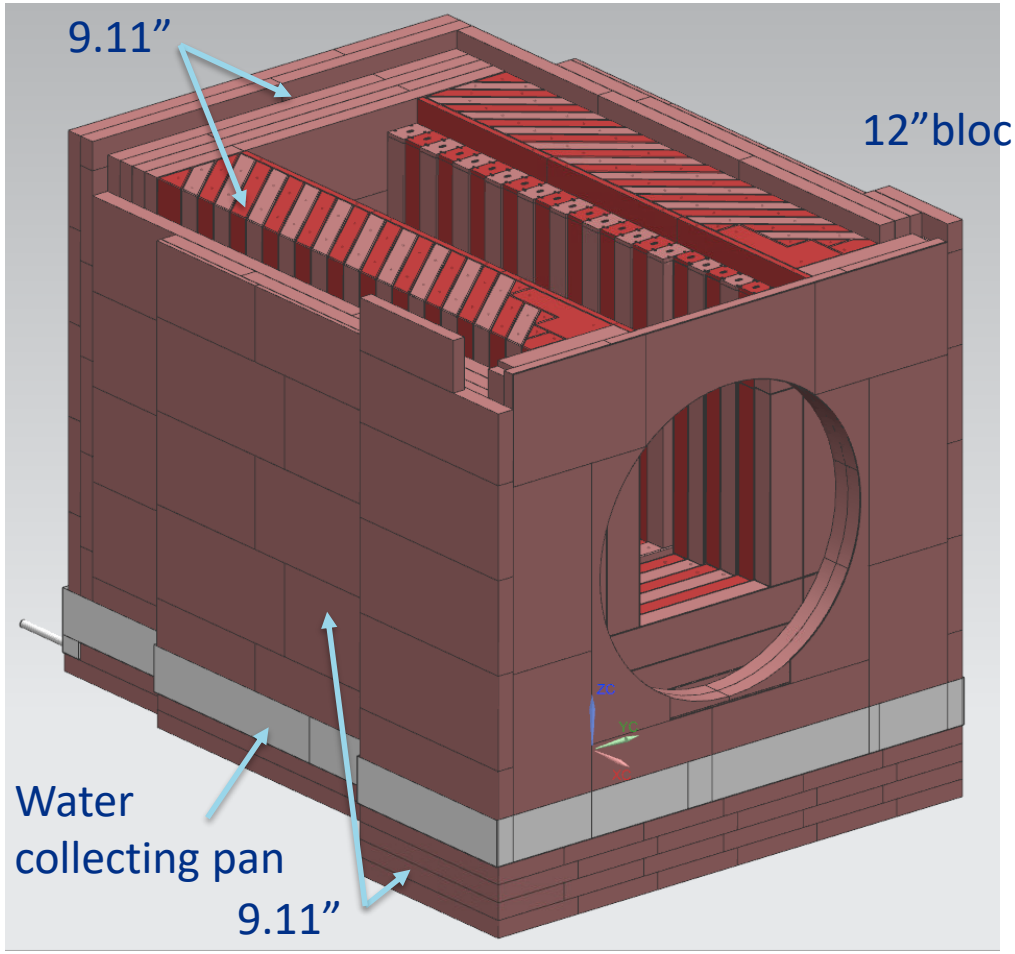


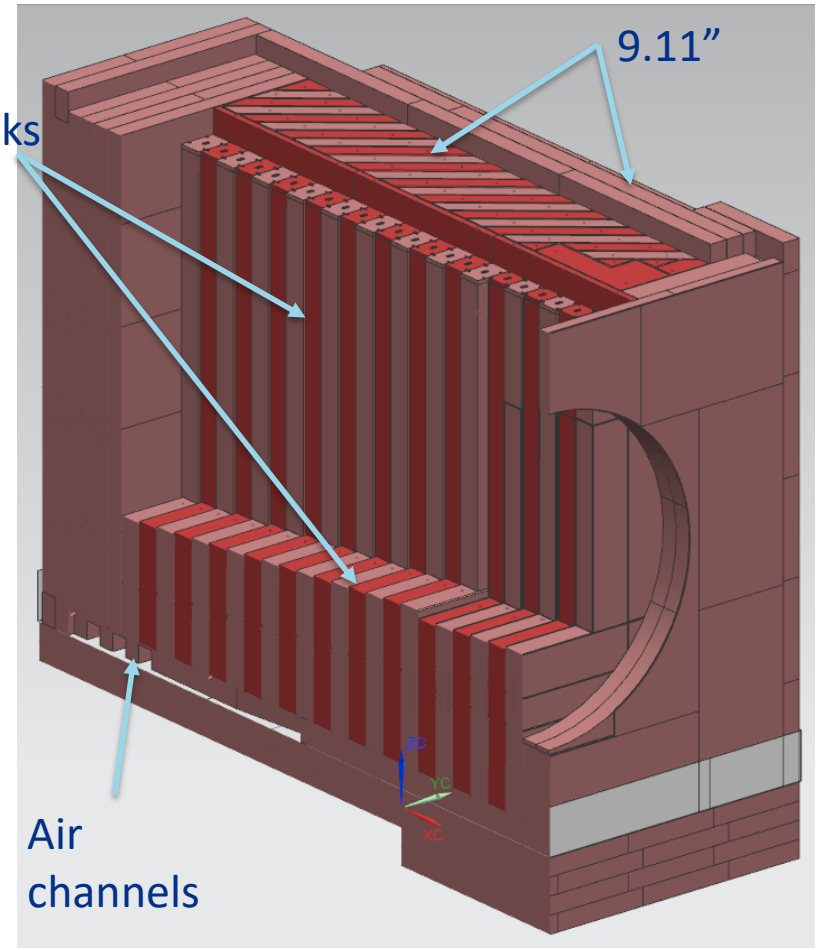




Steel shielding design

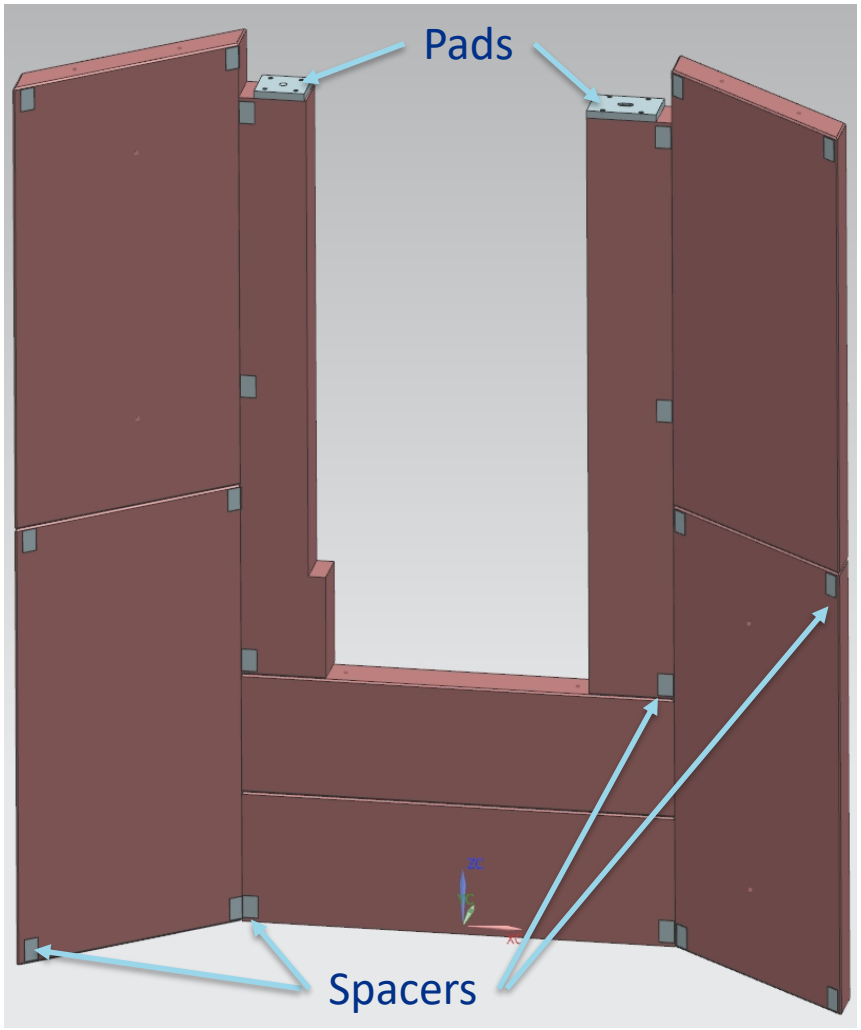
About 6 million pounds of steel are used in the absorber shielding. The most of shielding is made from 9.11 steel. Only the center module supporting blocks are made from 12” A36 steel.

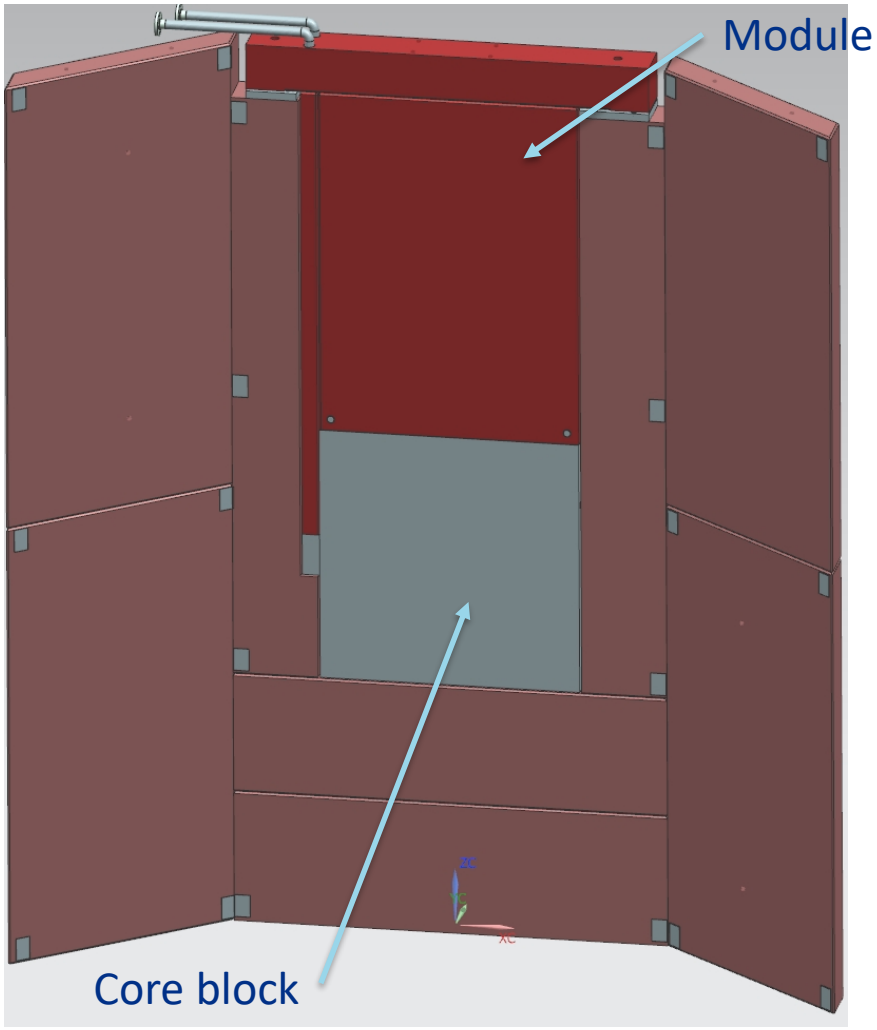




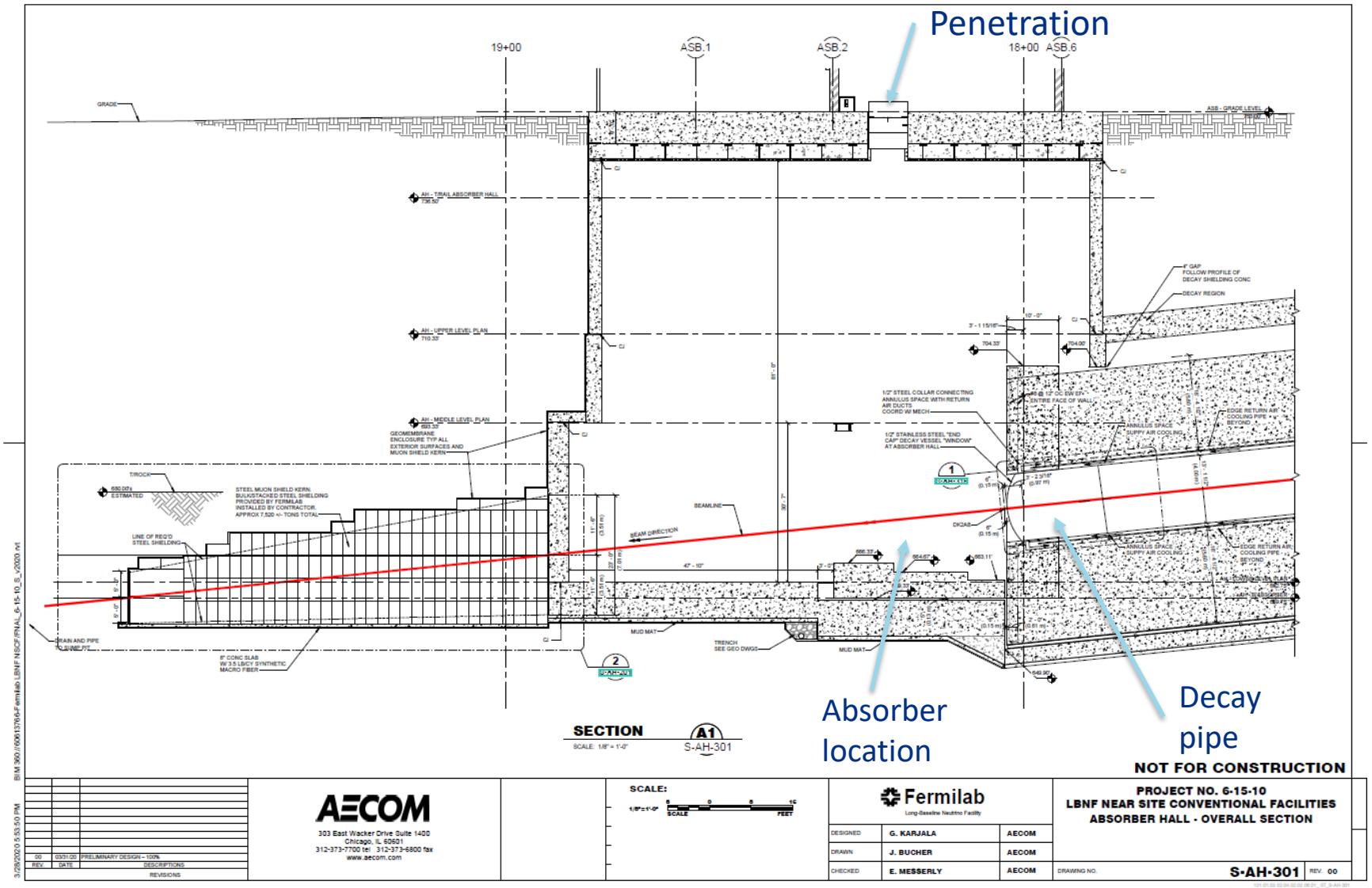
Steel shielding layer

The steel shielding is installed in the absorber by layers starting from upstream end of the absorber. 6”x4” spacers are welded to one side of the layer. Module support pads are bolted to the support blocks.



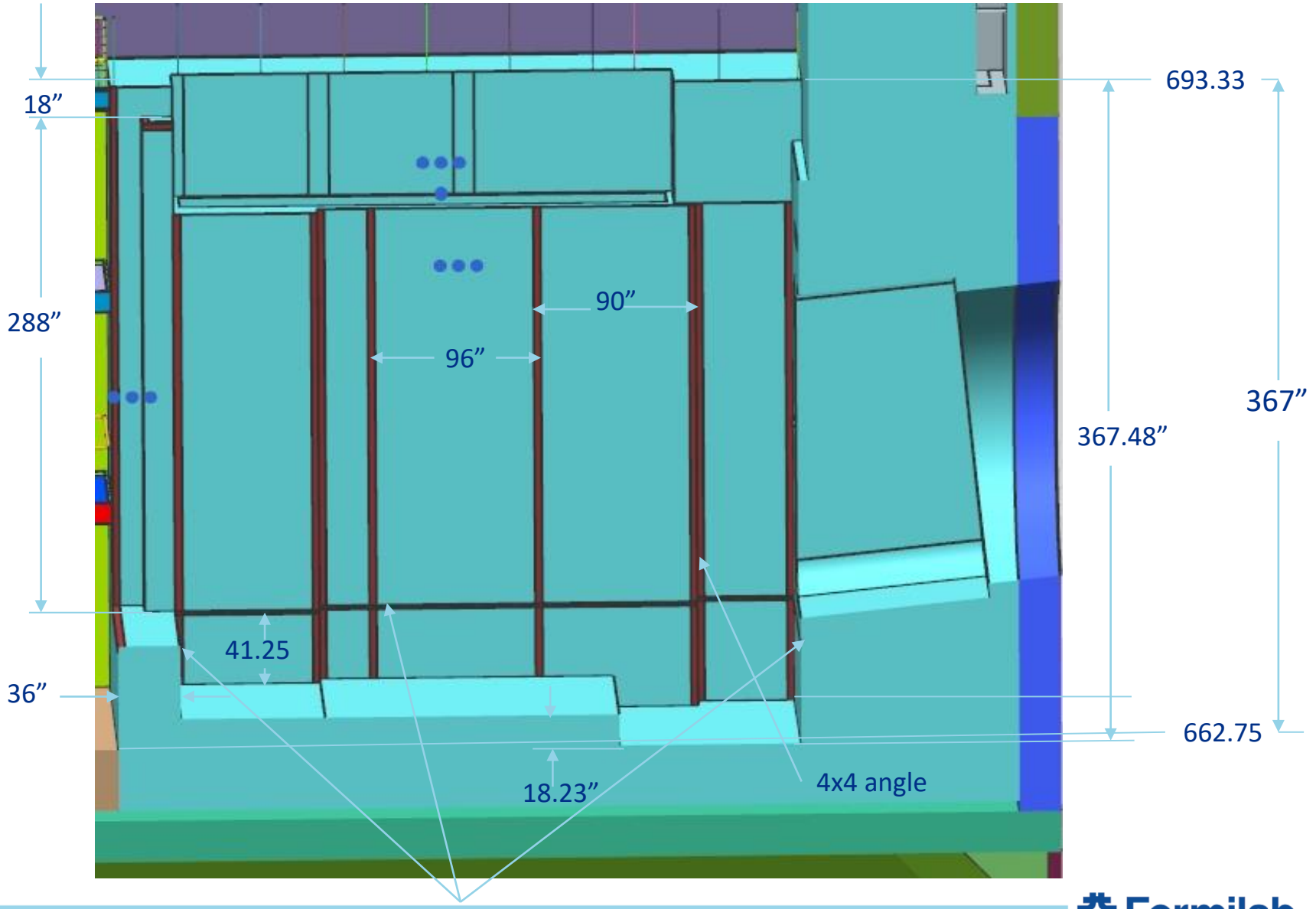


Absorber hall

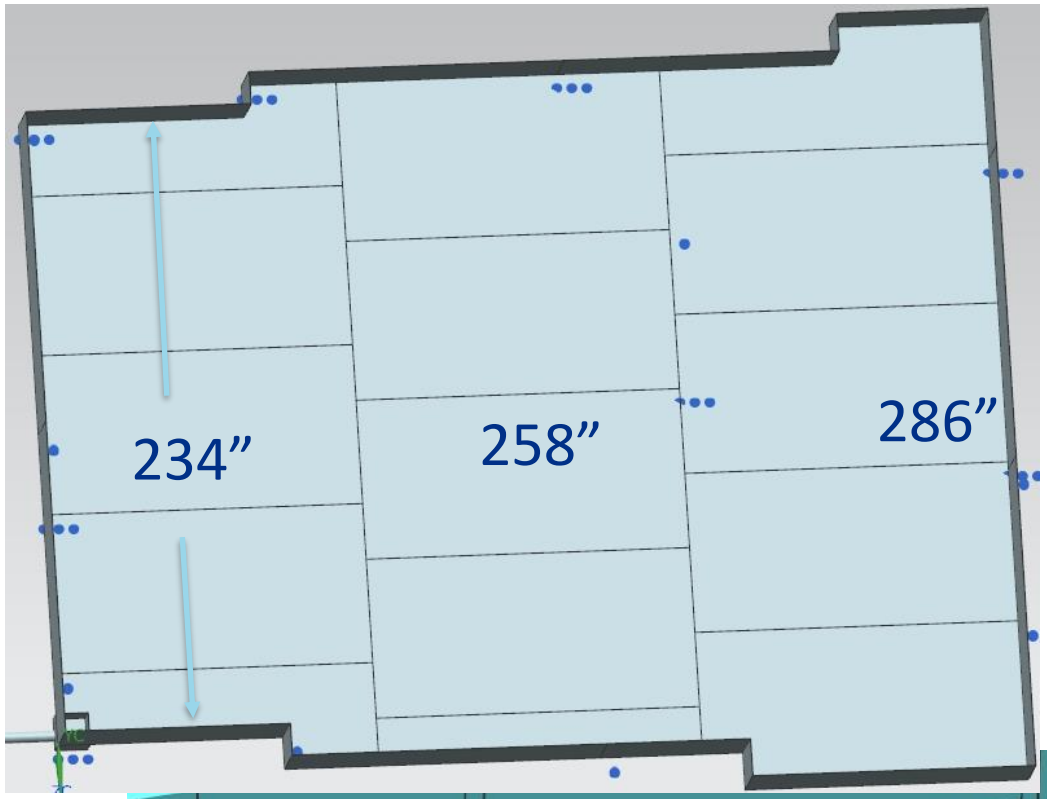


Absorber concrete bunker

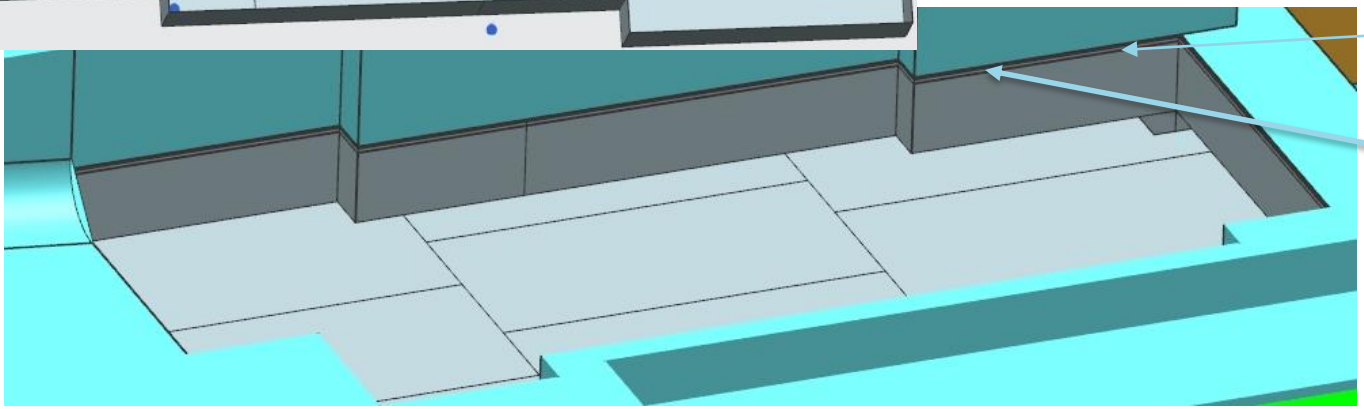
Steel strips are embedded into the concrete for the steel shielding welding.



Radioactive water collecting pan

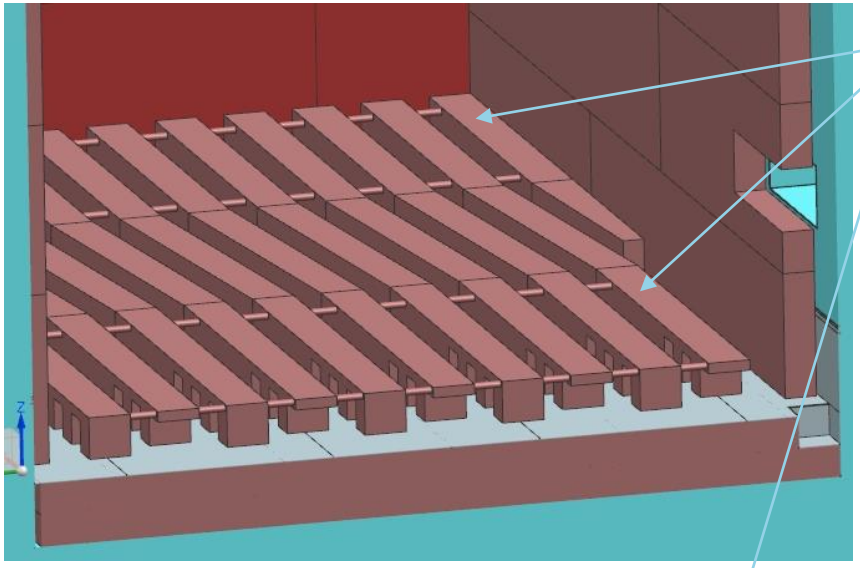


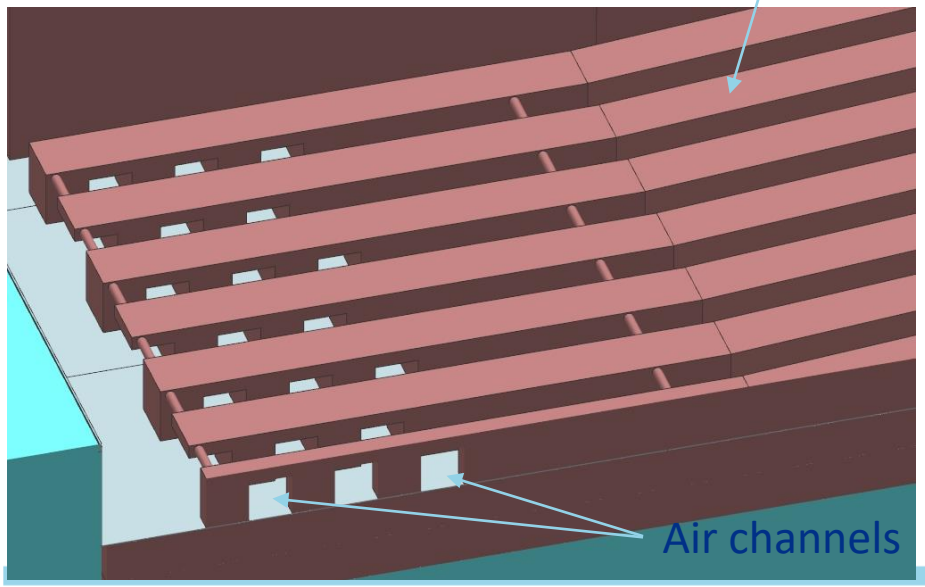
The pan is welded from the 48”x120”x ¼” stainless steel base plates and side plates 24 “ height and 1/8” thickness. The final weld of the pan is made in the absorber hall. Side plates are welded to the penetrated into the concrete steel strips. The pan is normally dry. It will fill up only when there is a leak in the water cooled components

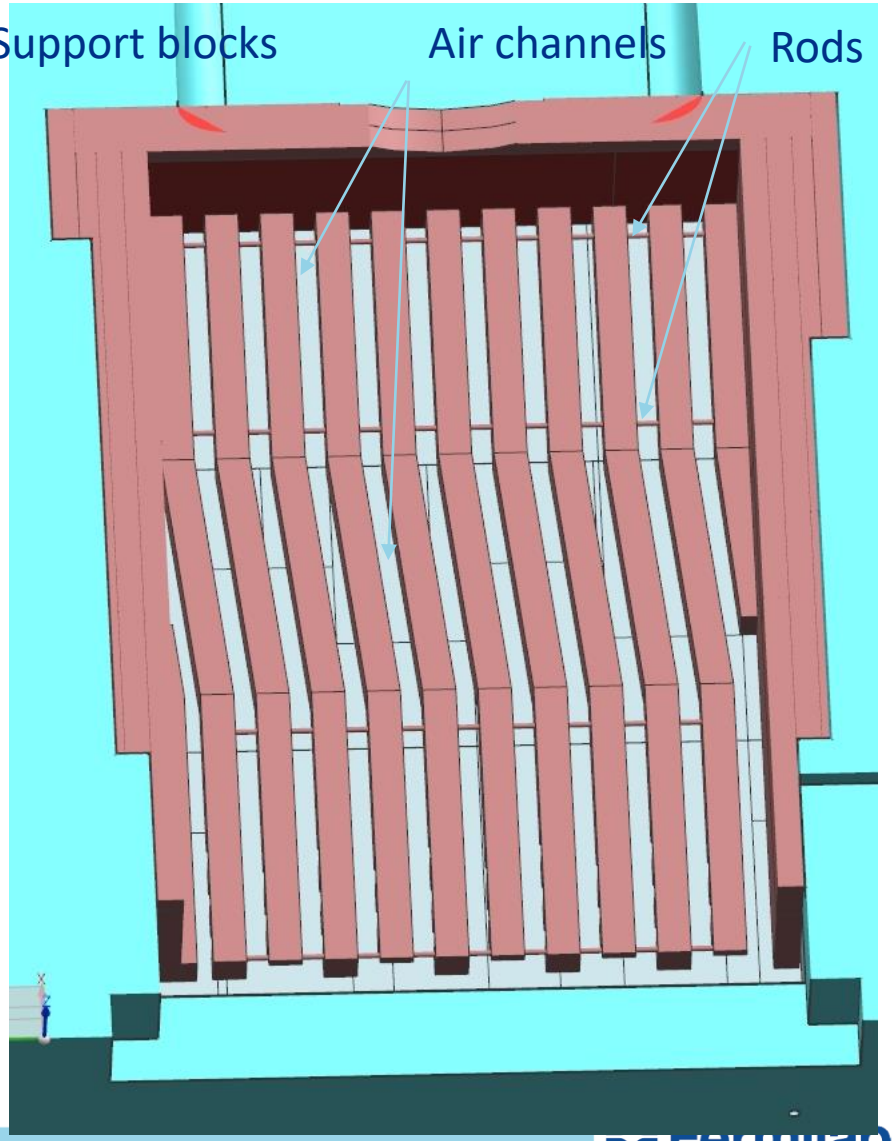


Support blocks-air channels

Steel 12”x12” blocks 10-113.5” long are installed on the stainless steel pan and joined together with steel rods. Blocks are not welded to the pan. The distance between block is eight inches.

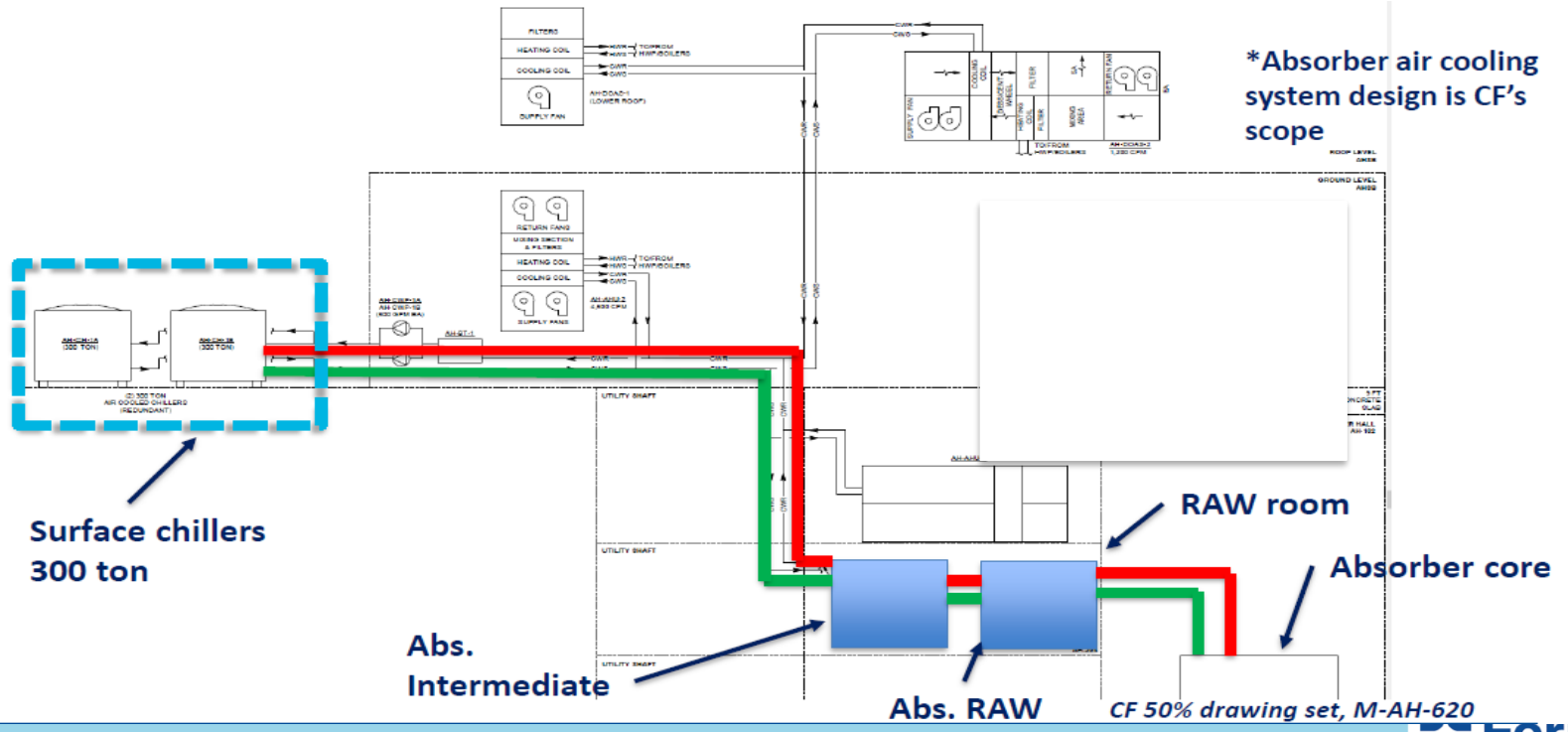






Absorber core cooling

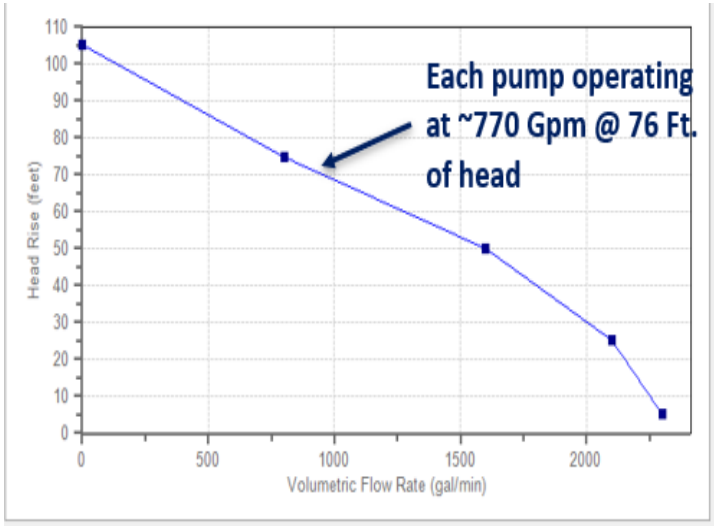
- The core of the absorber is water cooled.
- The cooling is provided by the LBNF Absorber RAW Cooling system. This is an ASME B31.3 Normal Fluid Service as per FESHM 5031.1.
- Preliminary design done for this system: DUNE-doc-17876.



Absorber core cooling

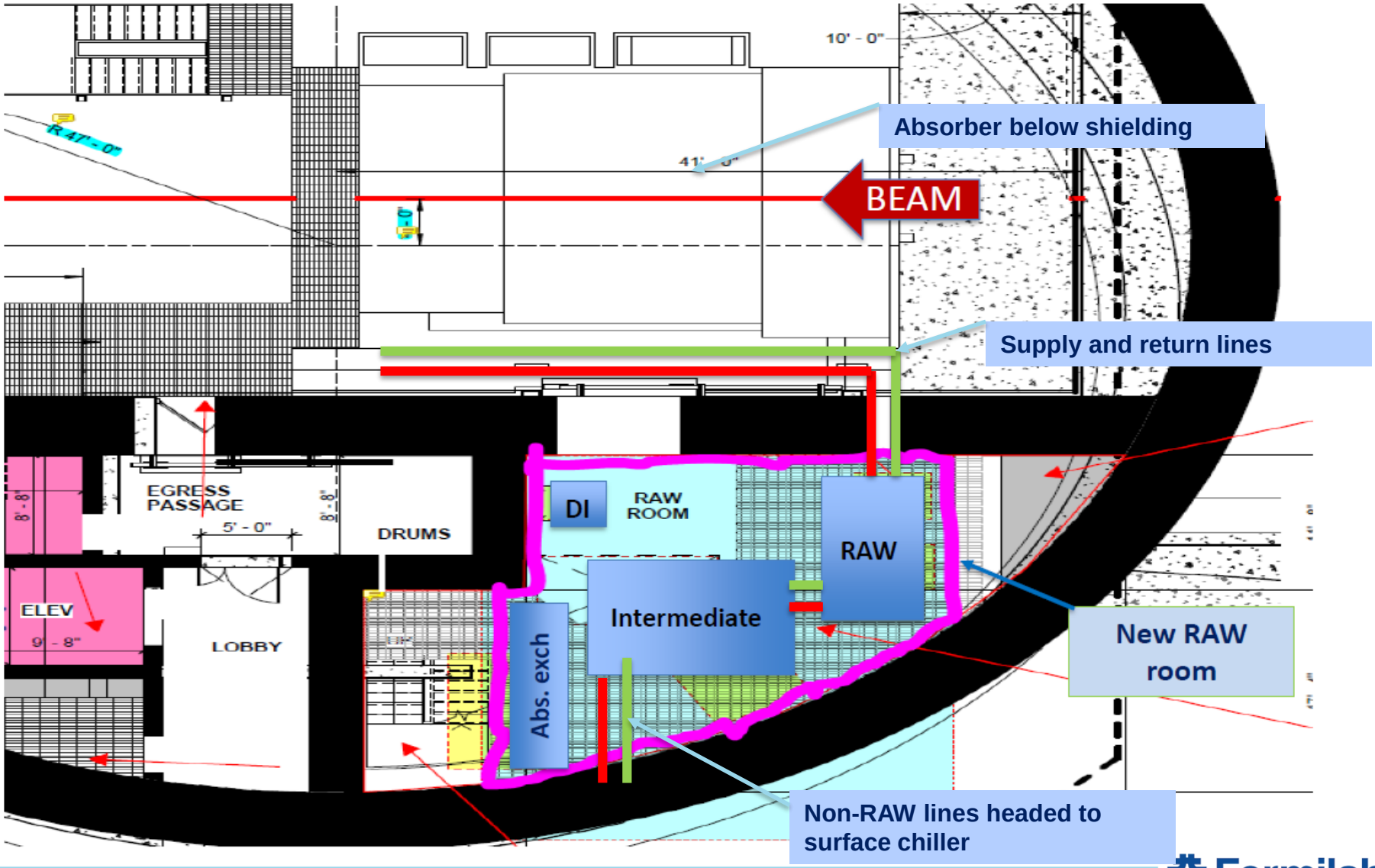
- Requirement of the system is to provide temperature regulated DI water to the core.
- Maintain an average velocity of 5-7 ft/s in all the gun-drilled cooling channels in core components.
- Minimum flow requirement for Absorber core components:

Type of block	Qty.	Number of loops per component	Flow per channel	Flow per component , Gpm	Total flow, Gpm
Aluminum spoiler	1	4	20	80	80
Aluminum mask block	4	2	15	30	120
Aluminum core block	13	4	20	80	1040
Steel core block	4	2	20	40	160
Minimum flow required for cooling @ 80 F inlet water temperature→					1400



Parameter	Value	Units	Remarks
System volume	~1500	Gal.	
System design temperature	130	F	
System operating temperature	80	F	
Maximum allowable working pressure	75	Psig	
System operating pressure	45	Psig	
Expansion tank operating Ar. Pressure	5	Psig	
System pump design horse power	40	Hp	2 pumps running, 1 stand-by spare
System design flow	1540	Gpm	
Design flow through the DI loop	48	Gpm	Includes side-stream filteration. 5 micron pre-DI and 20 micron post-DI
Design system resistivity low	3	MOhm-cm	
Design system resistivity high	5	MOhm-cm	
Tritium concentration	<1E6	pCi/ml	Absorber exchange system, periodic feed/bleed
Design flow through water cooled components	1492	Gpm	Spoiler, mask, Al-core, Steel- core
Design flow through (RAW side) the heat exchanger	405	Gpm	
Design flow (cold side) through heat exchanger	650	Gpm	Cold side means Absorber Intermediate system
Design temperature difference (RAW side)	10	F	
Design temperature difference (cold side)	6.2	F	
Design heat capacity	590	kW	
Design heat transfer surface area	95	Ft^2	

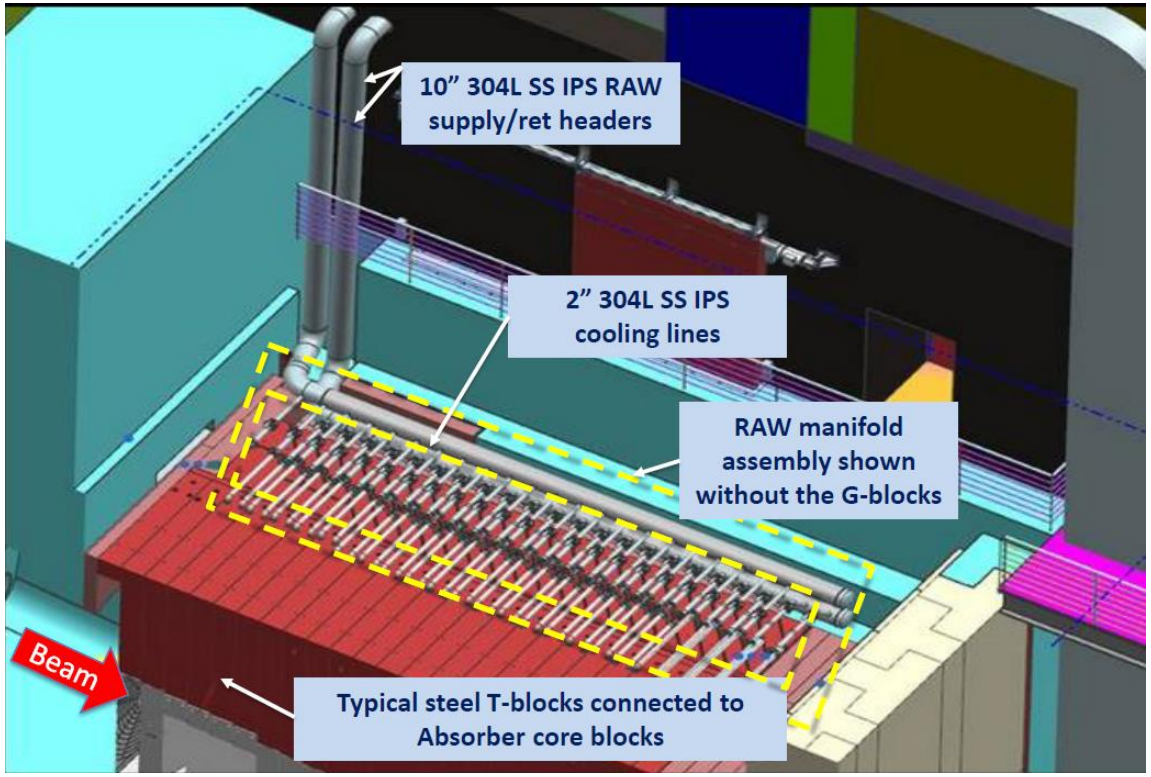
Absorber core cooling: System layout

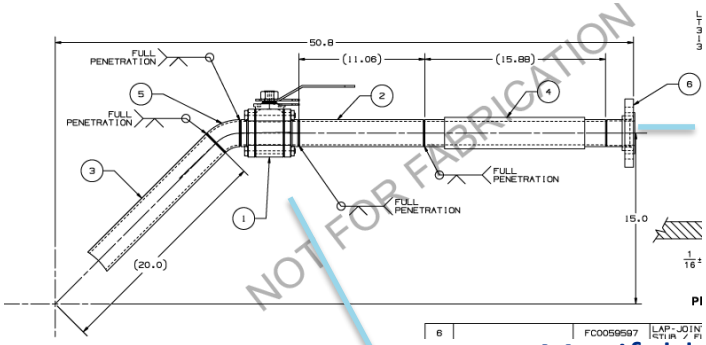


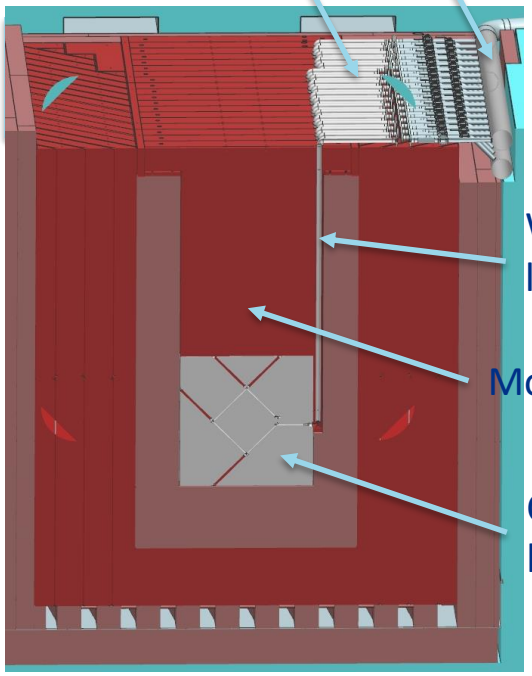
Fermilab

Absorber core cooling: System layout

Piping layout in LBNF Absorber Hall



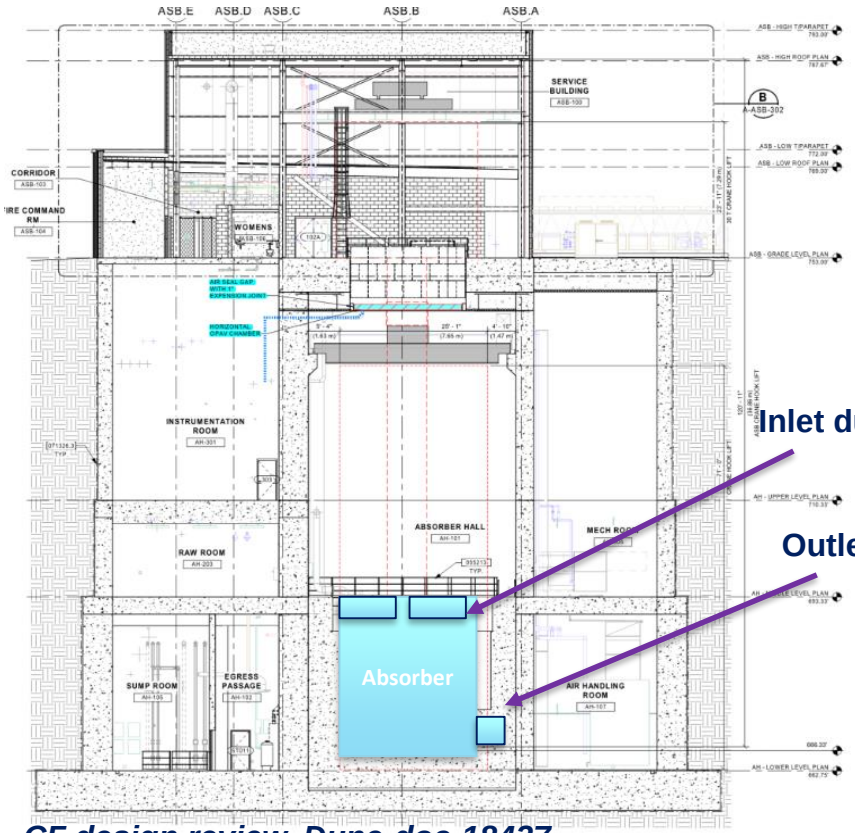




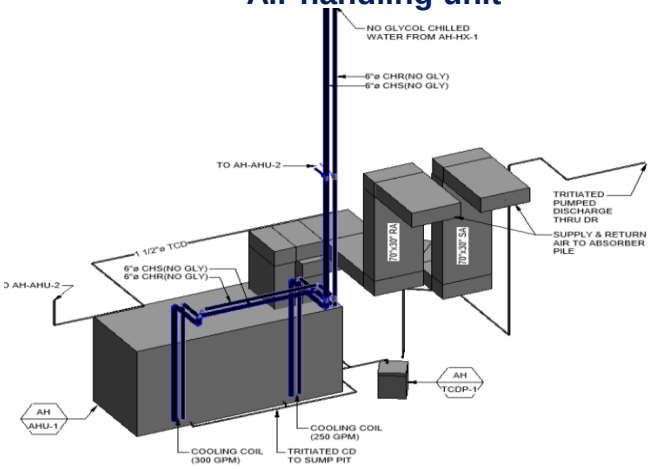
- **All piping parts and materials have been used without any failures on NuMI RAW systems since 2007.**
- **304L SS flanged connections to 6061-T6 flanged connections exist in the NuMI Absorber hall. Worked well since 2007.**

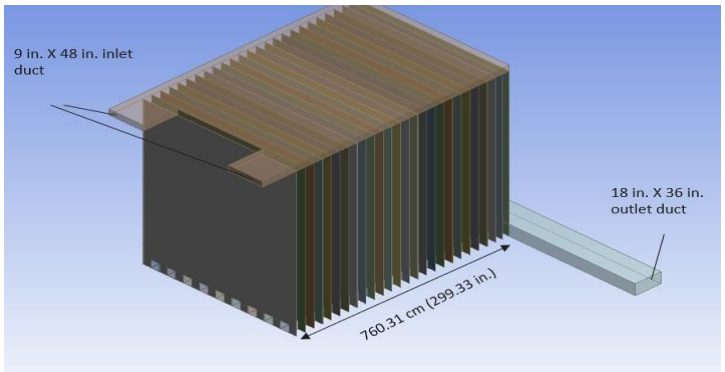
Steel shielding cooling

- Surrounding steel is air cooled.
- An air cooling system, designed by CF, delivers 25,000 CFM of air which blows in on top of the absorber blocks and passes through the 5-mm gaps between the blocks. Collects in the air channels at the bottom and enters the return duct at the back of the Absorber.



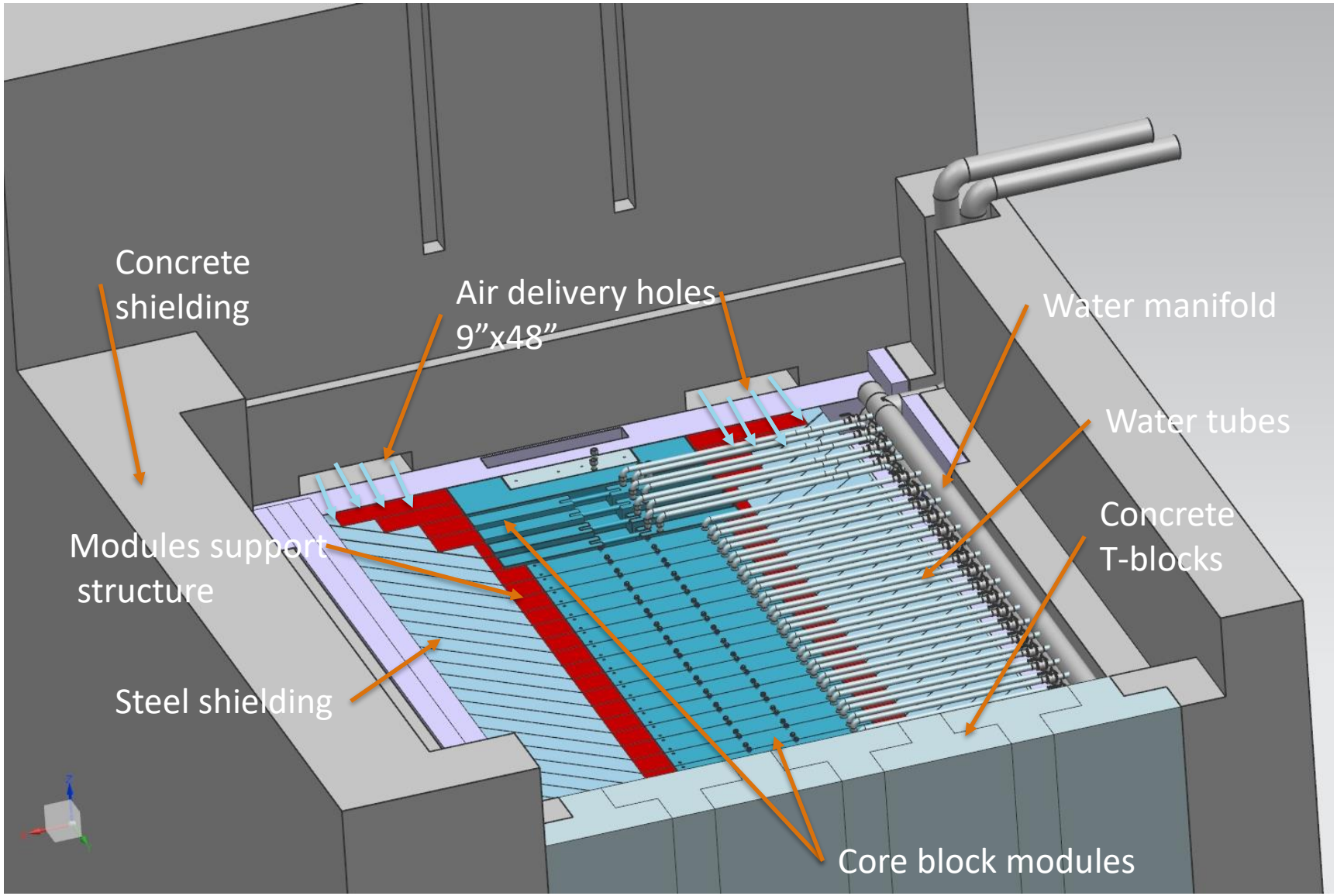
Air handling unit



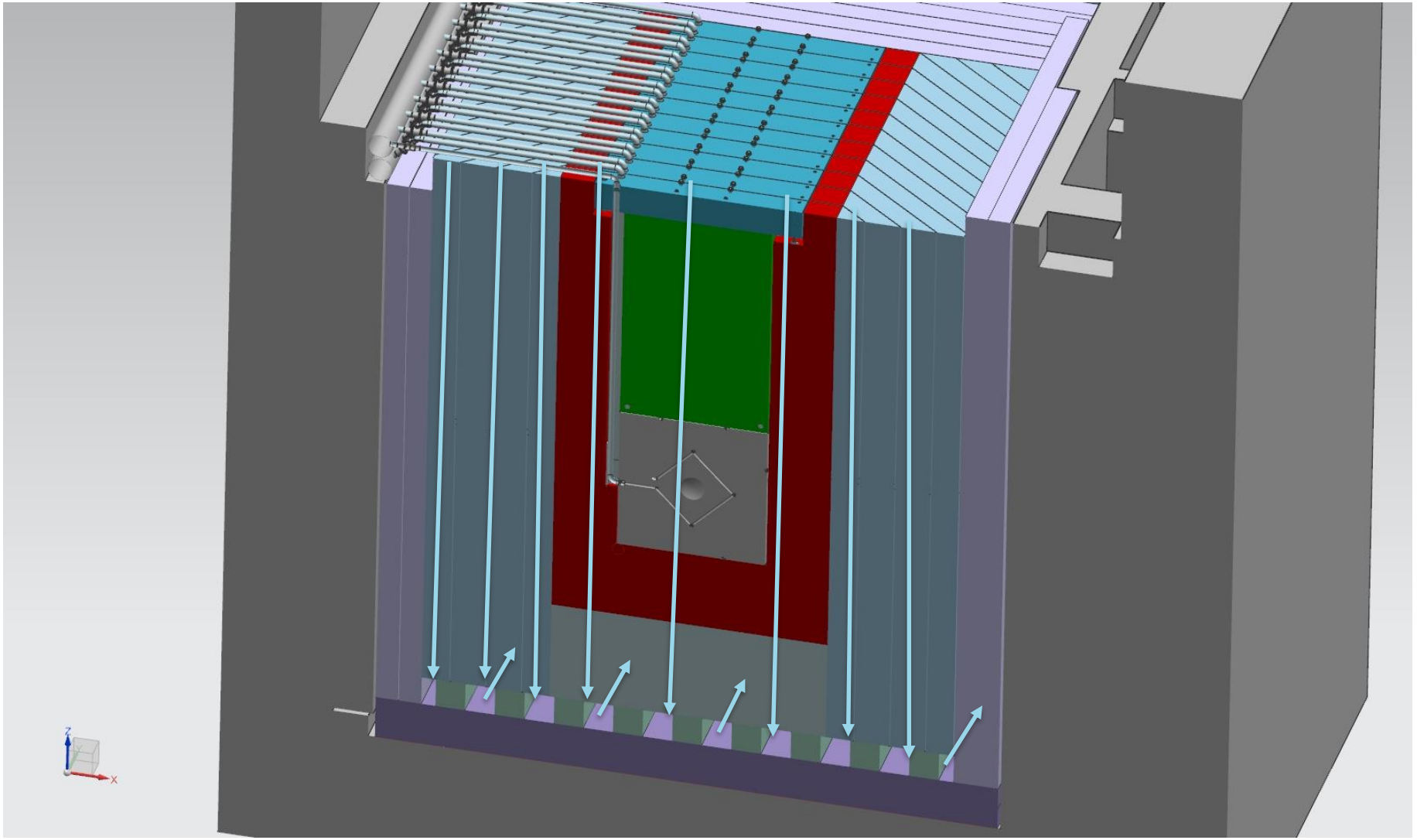


CF design review, Dune-doc-18427

Absorber components and air flow

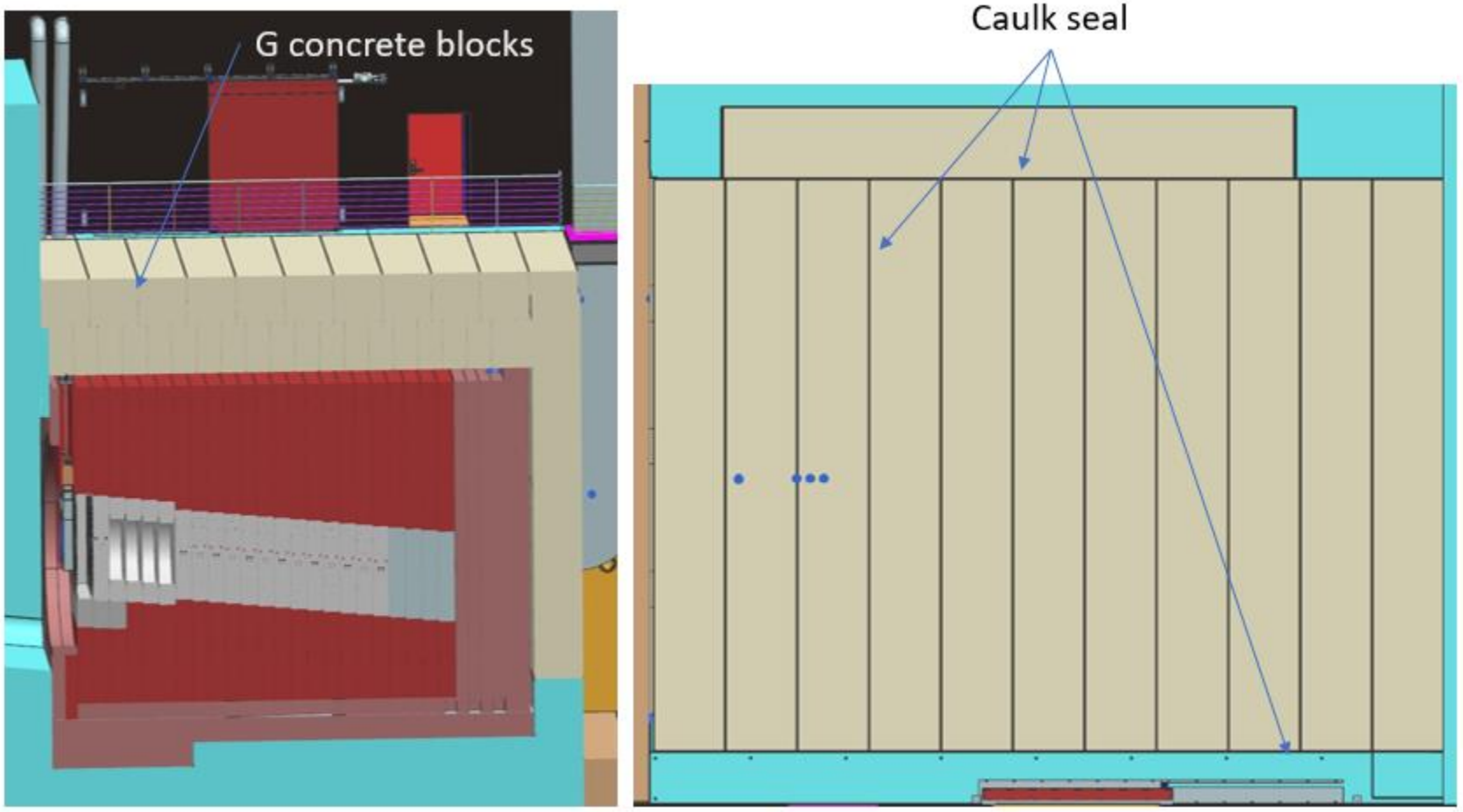


Absorber components and air flow

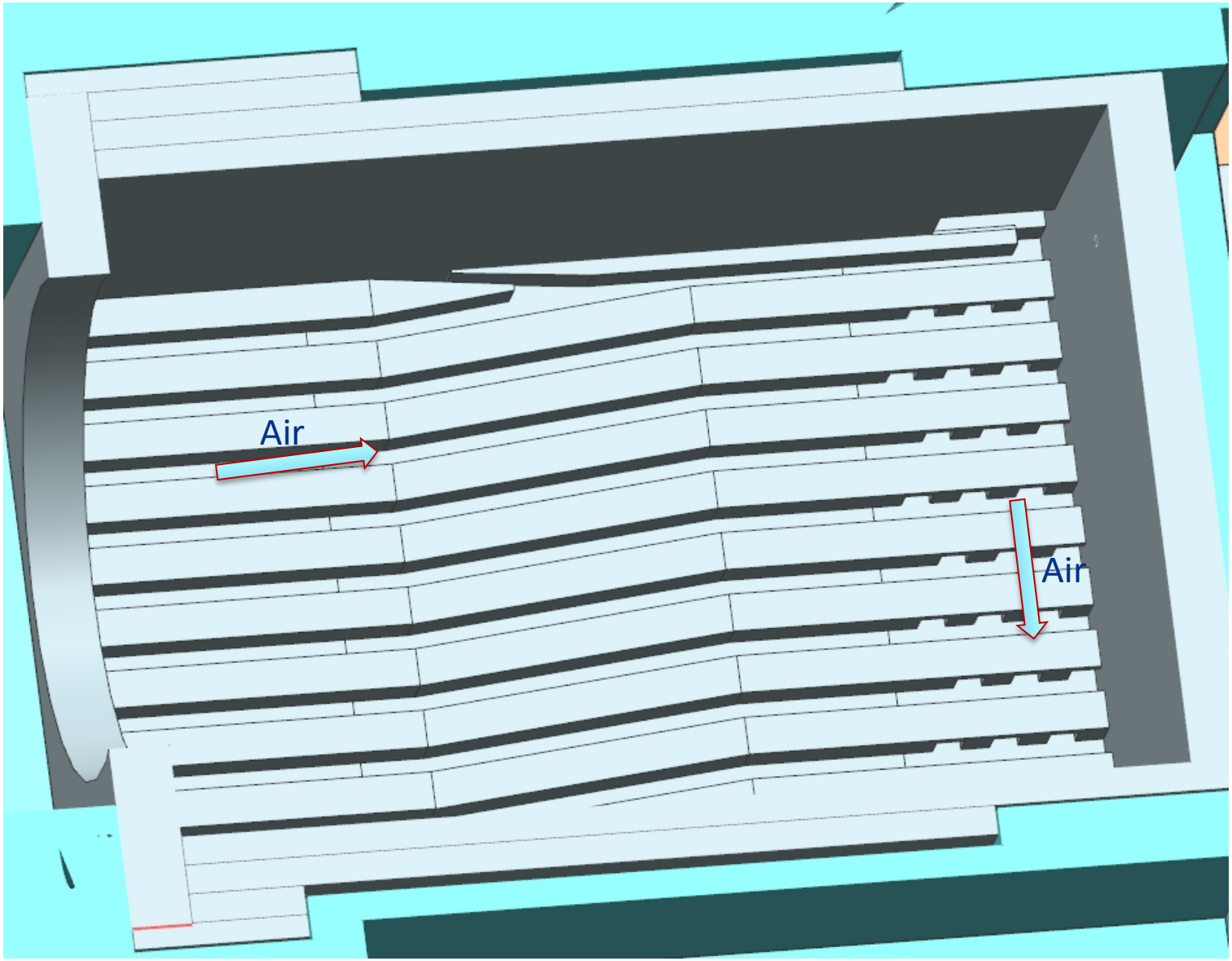


Absorber components and air flow

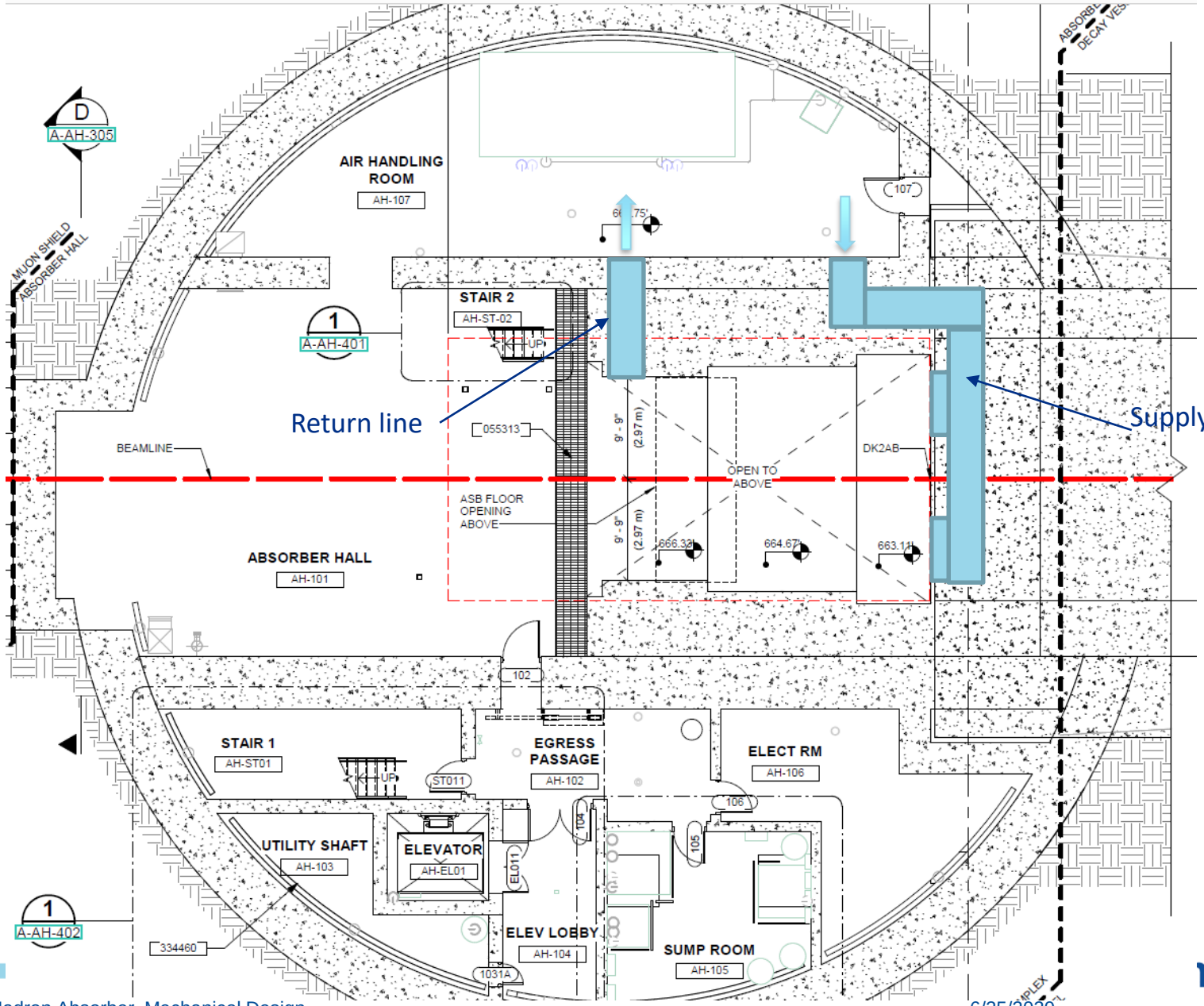
G-blocks on top sealed with caulk (Current NuMI scheme) prevents the air from escaping from the top



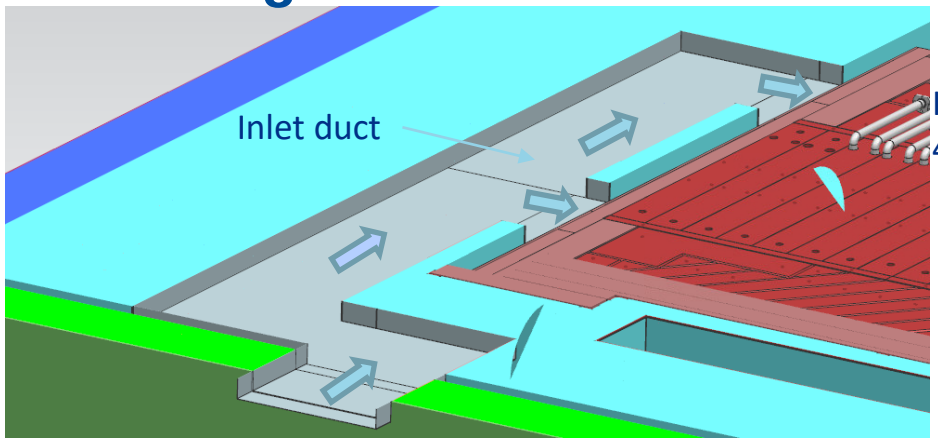
Absorber components and air flow



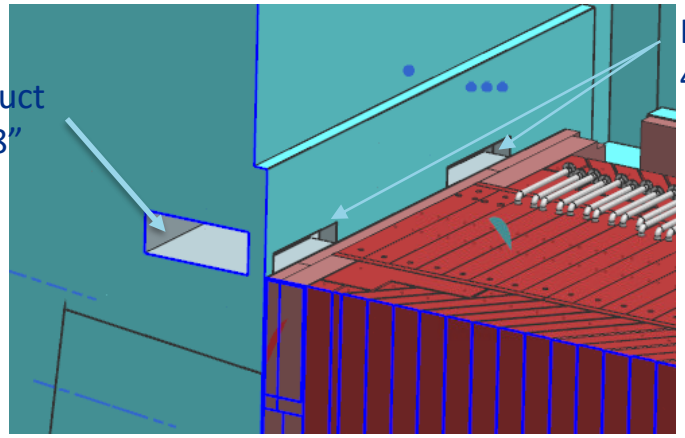
Air cooling ducts location



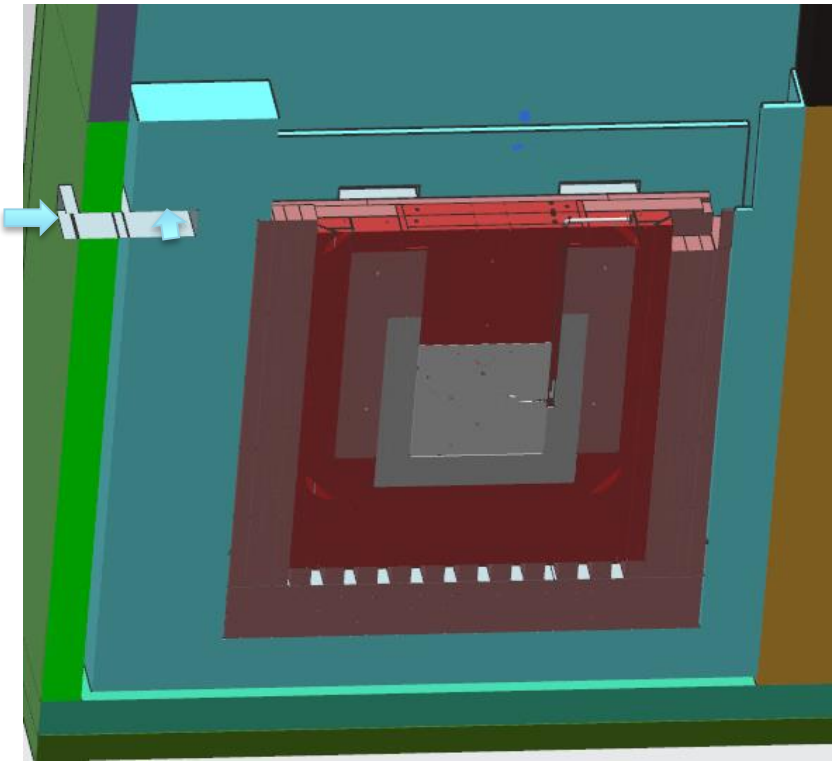
Air cooling ducts location



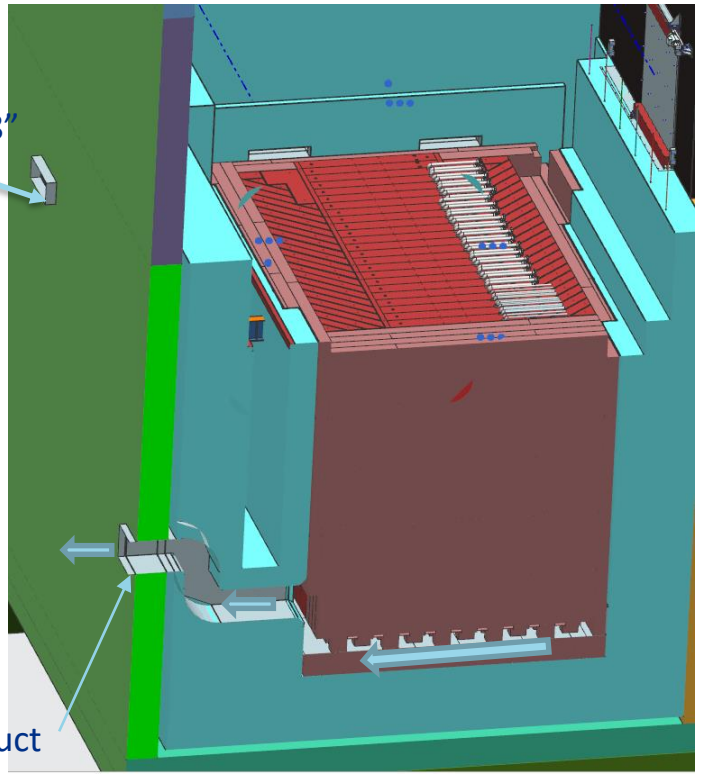
Inlet duct
48”x18”



Inlet duct
48”x9”



Inlet
duct 48”x18”

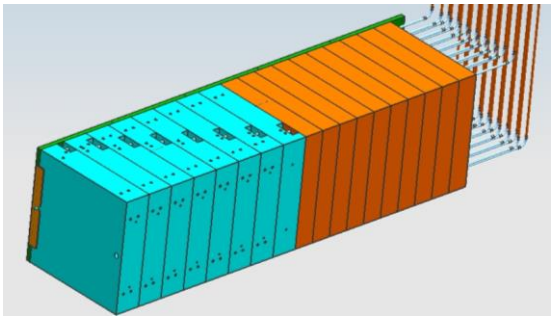


Outlet duct
48”x36”

Fermilab

Core block prototype and weld samples

- The Absorber will have 6061-T6 Al core blocks.
- The size of these blocks are bigger than the Aluminum core blocks manufactured for
- the NuMI Absorber (51” x 51” x 12”).



- Also, the gun-drilled cooling channels in the spoiler and the core blocks are more complex than those done for the NuMI blocks.
- Thus, the prototype was built to understand the manufacturing, testing, and qualification processes involved. These will be adapted during the fabrication of the actual Aluminum blocks for the Absorber.

Core block prototype and weld samples

- The core block was built to the following specification:
  - ED0007988--LBNF Aluminum Absorber Core Block Prototype, Rev. B.

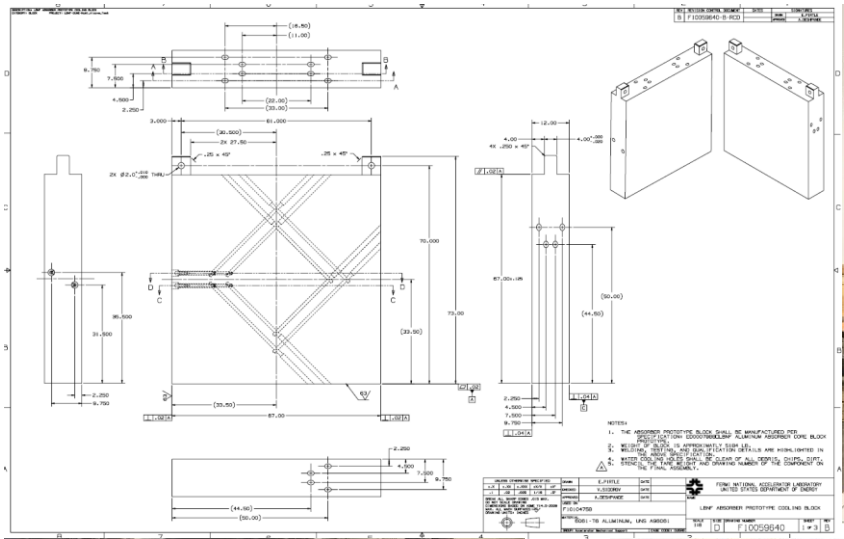
- Specification was developed with Target Systems Department engineers who have experience with Aluminum components.

- Specification included heat treatment in accordance with AMS 2772E: Heat Treatment of Aluminum Alloy Raw Materials using a polymer quench before machining operations.

- The core block was ultrasonically inspected and qualified in accordance with ASTM B-594 Class A.

Core block prototype and weld samples

- 67” X 67” X 12” Al core block manufactured at Magna Machine, Inc in Ohio



- **Material: 6061-T6 Aluminum**
- **Dimensions: 67”W X 67”H X 12”**
- **Cooling lines: 4**
- **Weight: 5180 lb**

Gun-drilled channels openings. Not plugged yet. Weld detail needs to be machined here

Core block prototype and weld samples

- Welding of the cooling lines to the Al blocks will be done at Fermilab.
- Weld samples were made and tested to come up with a weld joint that would last the operational life of the Absorber—capable of passing most stringent Al weld qualifying specifications.
- Following document was used to generate WPS, PQR, and WPQ for the weld joints that were tested:

PROCEDURE QUALIFICATION RECORD (PQR)

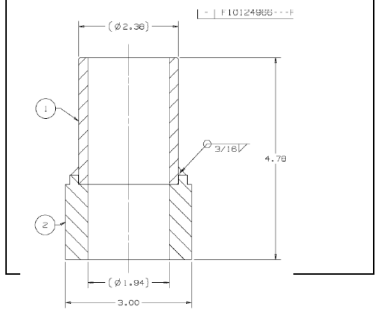
1. Procedure Qualification ☐ or 2. Procedure Verification ☐

COMPANY FERMI NATIONAL ACCELERATOR LABORATORY BY ABHISHEK DESHPANDE
PQR No. RF 801 DATE
DRAWING No. F10124966 REV. DATE
SUPPORTING DOC Nos. ED0000862, REV. 04
WELDING PROCESS(ES) GTAW TYPE MANUAL
Manual, Semi-Automatic, Automatic, Robotic

JOINTS

JOINT TYPE FILLET
BACKING NONE
BACKING MATERIAL (TYPE) NONE
GLOVES FOR HANDLING PARTS NITRILE
CLEANING AGENT FOR PARTS ISOPROPYL ALCOHOL
PARTS WIPE-DOWN MATERIAL KIMWIPES
SCRAPING NEW, CLEAN, CARBIDE SCRAPING TOOL
SCRAPING DONE IN ONE DIRECTION
POST SCRAPING TREATMENT BLOW CLEAN DRY AIR
OTHER DO NOT RE-SPRAY THE WELD AREA WITH ALCHOL OR OTHER CLEANERS AFTER BLOWING DRY AIR. WEAR CLEAN NITRILE GLOVES AT ALL TIMES.

Joint Details



Horn & Target Vital Component Welding Guidelines for Aluminum

ineering Document No. ED0000862, Rev. 04

AUTHOR(S):
Cory F. Crowley / Michael W. Mcgee

REVIEWER:
Kris E. Anderson / Patrick G. Hurh

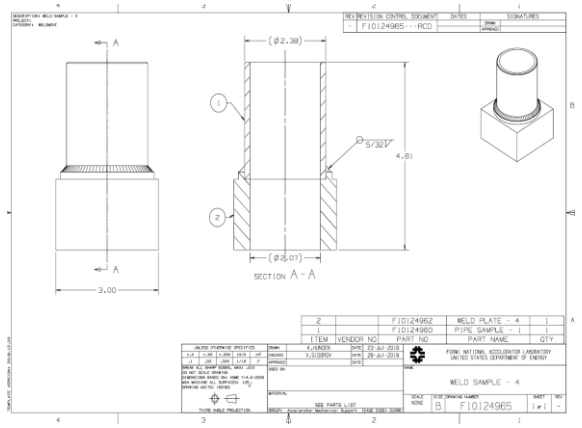
APPROVER:
Kris E. Anderson

***Note that these PQRs are not ASME, AWS qualified documents. They were made purely to keep track of how each sample was welded**

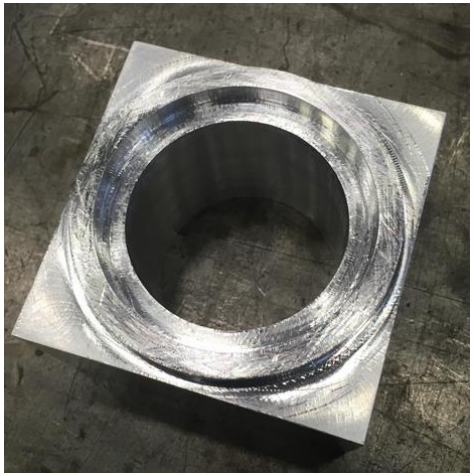
Core block prototype and weld samples

The weld samples were tested as per NAS1514 Class I.

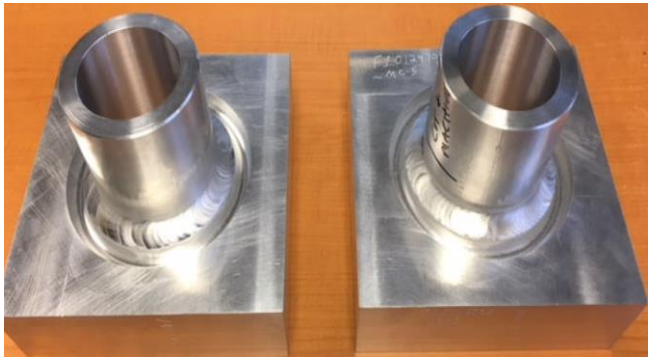
Part drawing



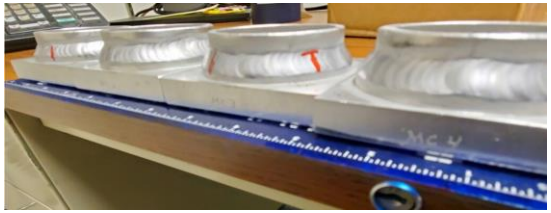
Scraped part



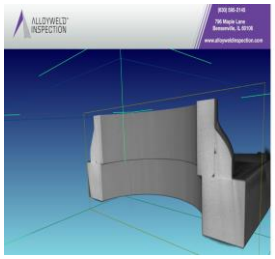
Welded samples

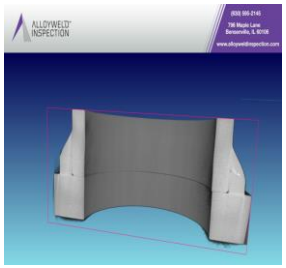


Cut Samples



Radiography/CT-scans





Radiography reports

ALLOYWELD™ INSPECTION

Alloyweld Inspection Co., Inc.
Bldg. 1: 796 Maple Lane Bensenville, IL 60106
Bldg. 3: 840 Church Road Elgin, IL 60123
Phone: 630.595.2145
Fax: 630.595.2128
www.alloyweldinspection.com

X-RAY READER SHEET

TO: FERMI-LAB
KIRK & WILSON STREET
BATAVIA, IL. 60510

DATE: FEBRUARY 07, 2020
ORDER NO: 665264
REGISTER NO: 84531
WORK ORDER NO: 39972
PAGE 1 OF 1

INSPECTION INFORMATION

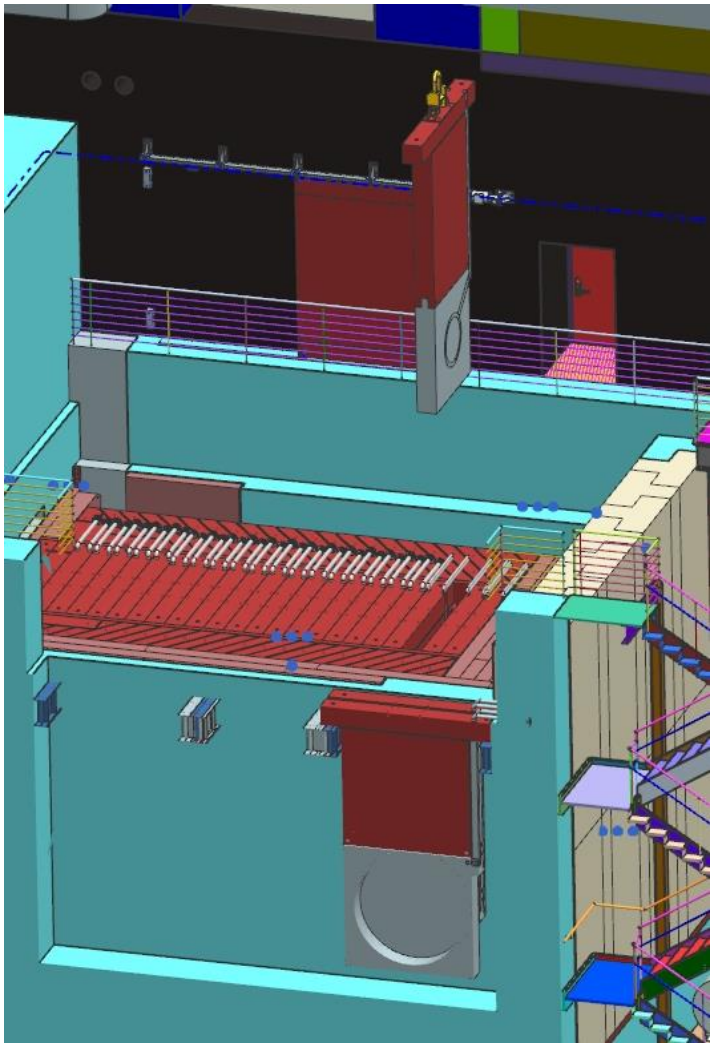
PART NUMBER	WELD SAMPLES	MATERIAL	6061 ALUMINUM	HEAT CODE	
FILM NUMBER	F564	NO OF VIEWS	4	NO OF FILM	(16)CR SHOTS

PROCESSED IN ACCORDANCE WITH:
DIGITAL RADIOGRAPHY PER NAS 1514 REV 3, CLASS 1
(WELD SAMPLES - 3" X 3" X 1-1/4" REV *)

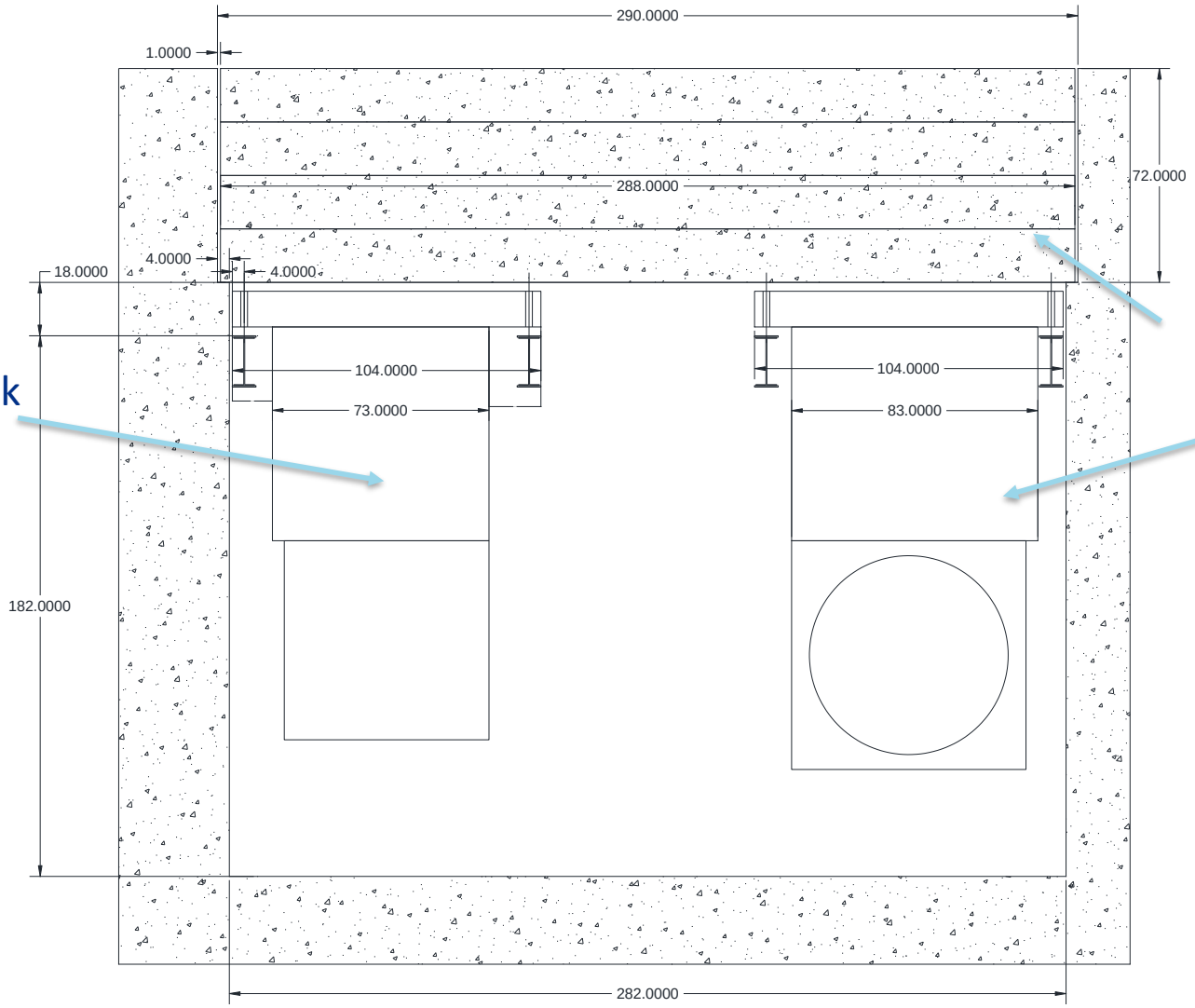
X-RAY SERIAL NUMBER	Accept	Non-Conforming	Incomp Penetration	Lack of Fusion	Cracks	Porosity	Undercut	Elong Indication	Indusion	REMARKS OR OTHER DISCONTINUITIES
SN: MC1 V1	X									
V2	X									
V3	X									
V4	X		X							ROOT
SN: MC2 V1		X		X						
V2		X		X						
V3		X		X						
V4		X		X						
SN: MC3 V1	X								X	TUNGSTEN
V2	X									
V3	X									
V4	X									
SN: MC4 V1	X									
V2	X								X	TUNGSTEN
V3	X									
V4	X									

Core blocks remote handling

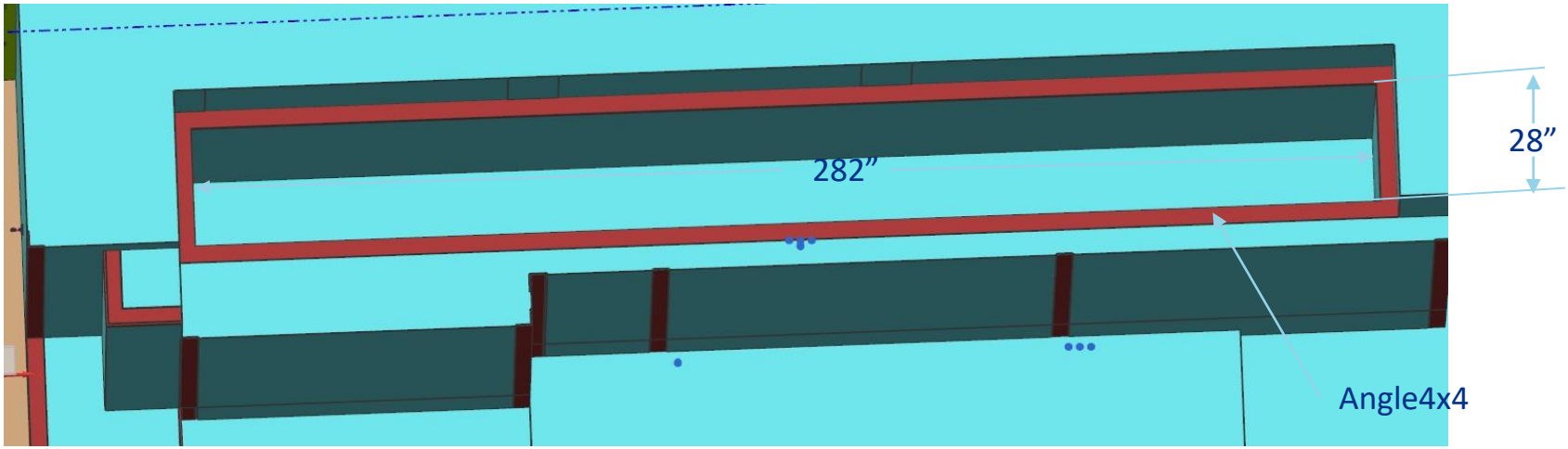
Two sections of the morgue can be occupied by four absorber core blocks with modules and middle section is for hadron monitor localization.

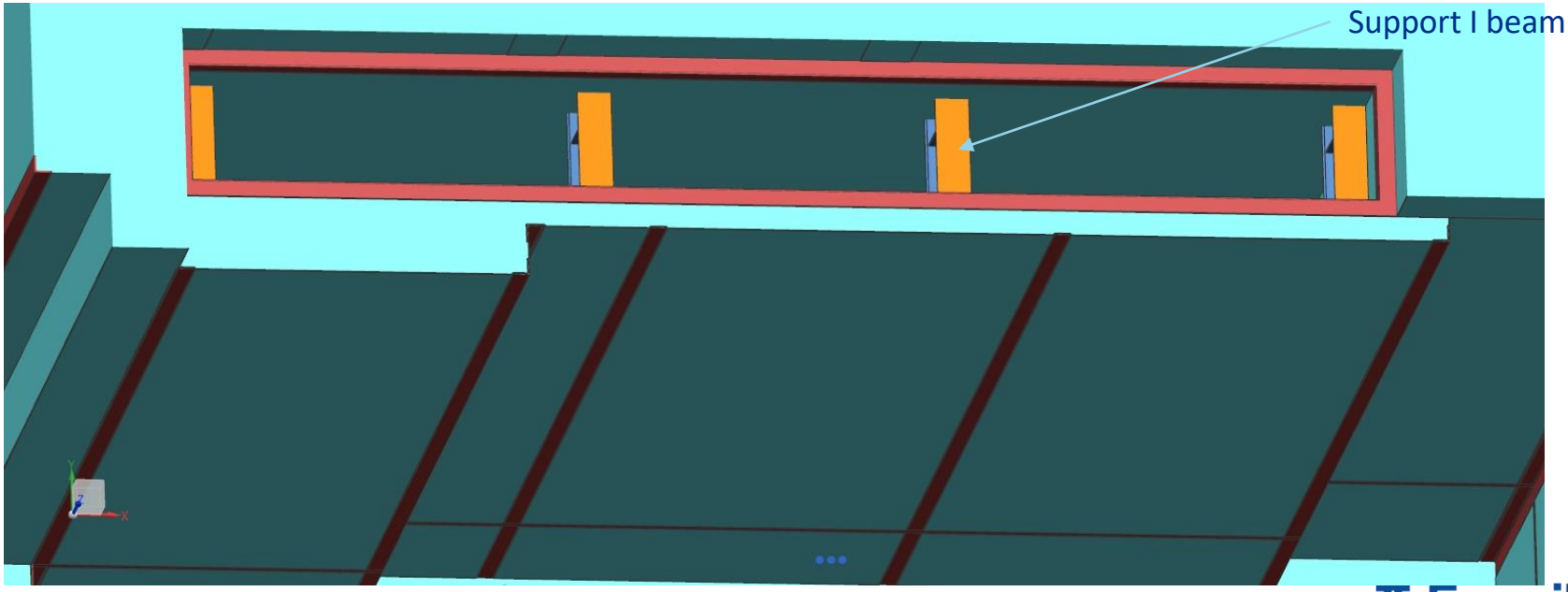


Absorber morgue dimensions



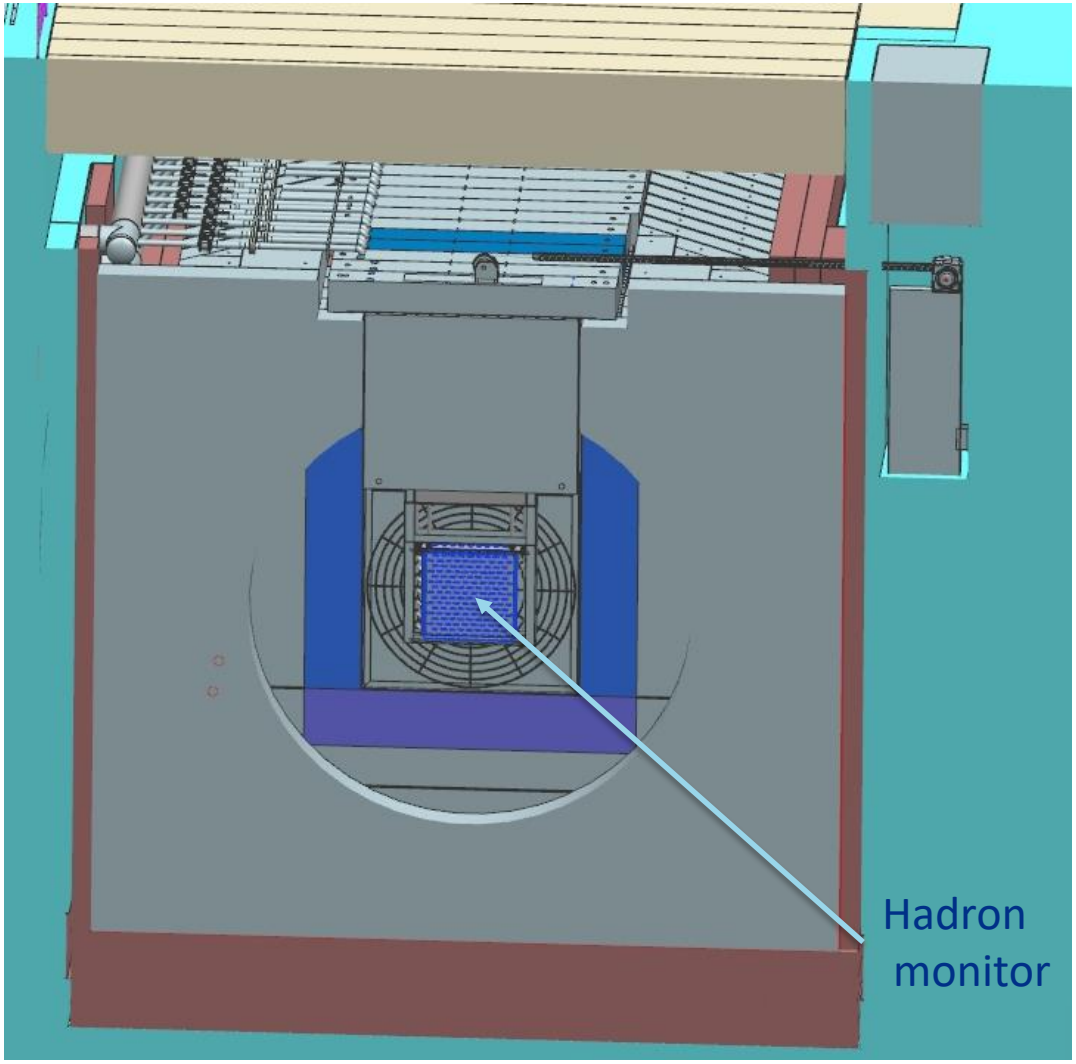
Absorber Morgue

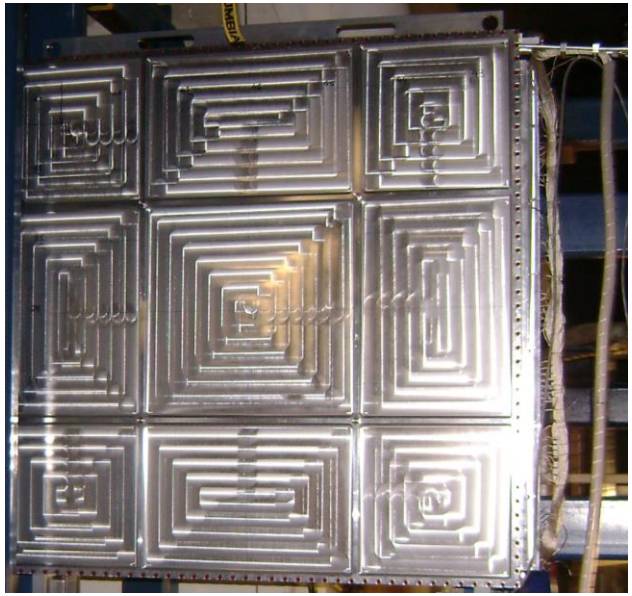


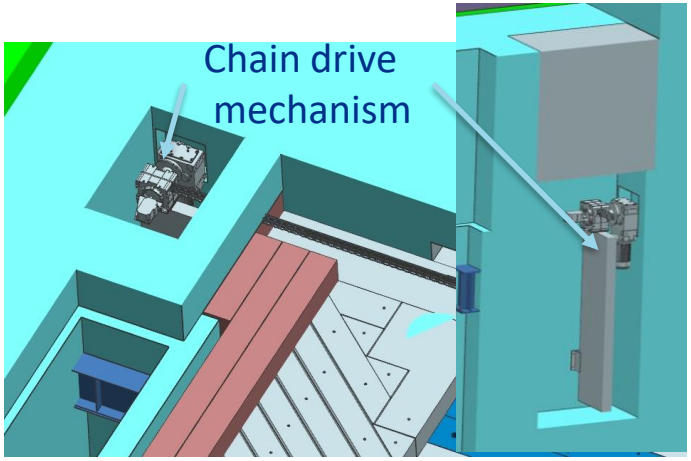


Hadron Monitor

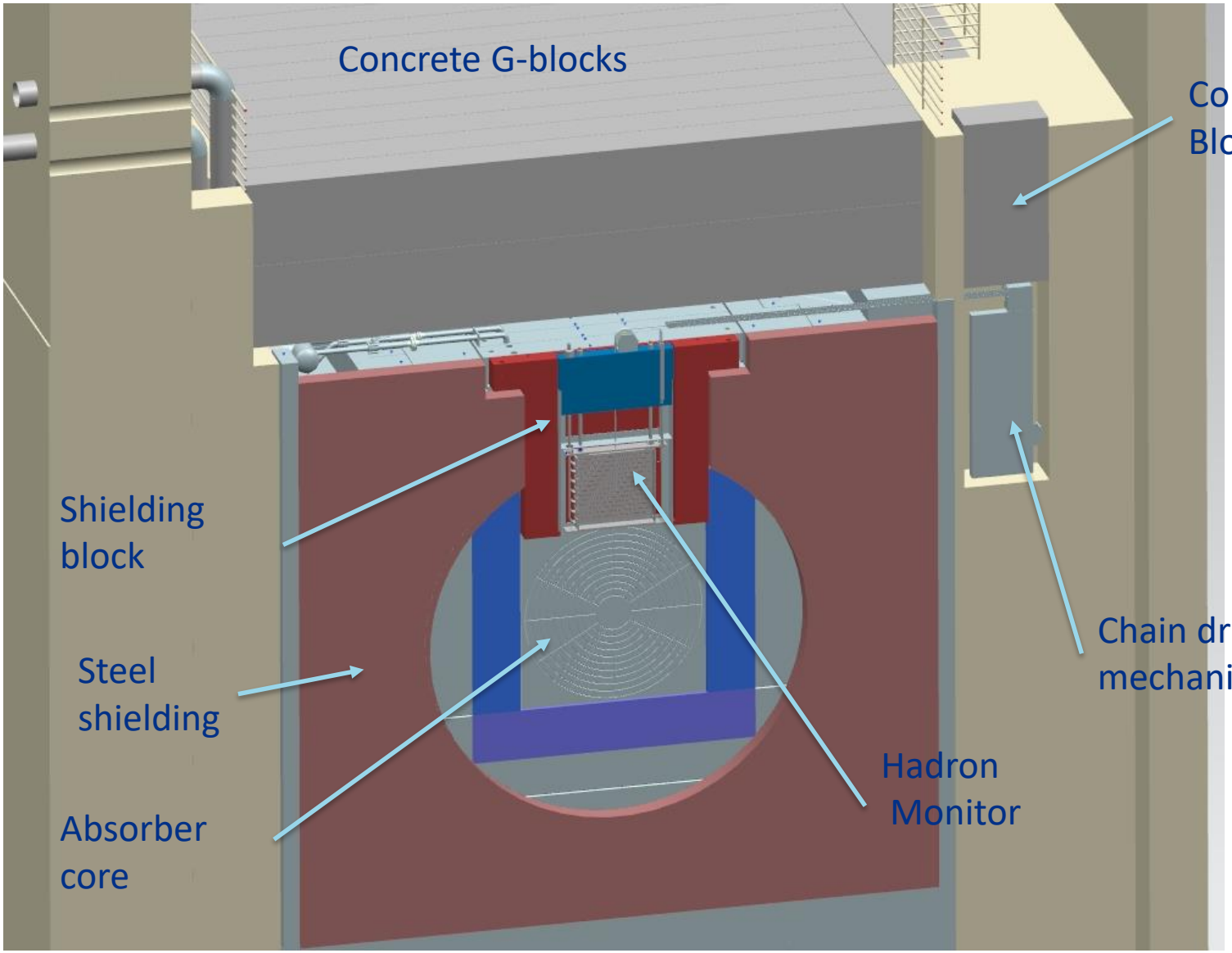
The Hadron Monitor is installed in the front of the absorber core blocks. The NUMI Hadron Monitor design removable from the beam is used in this presentation.



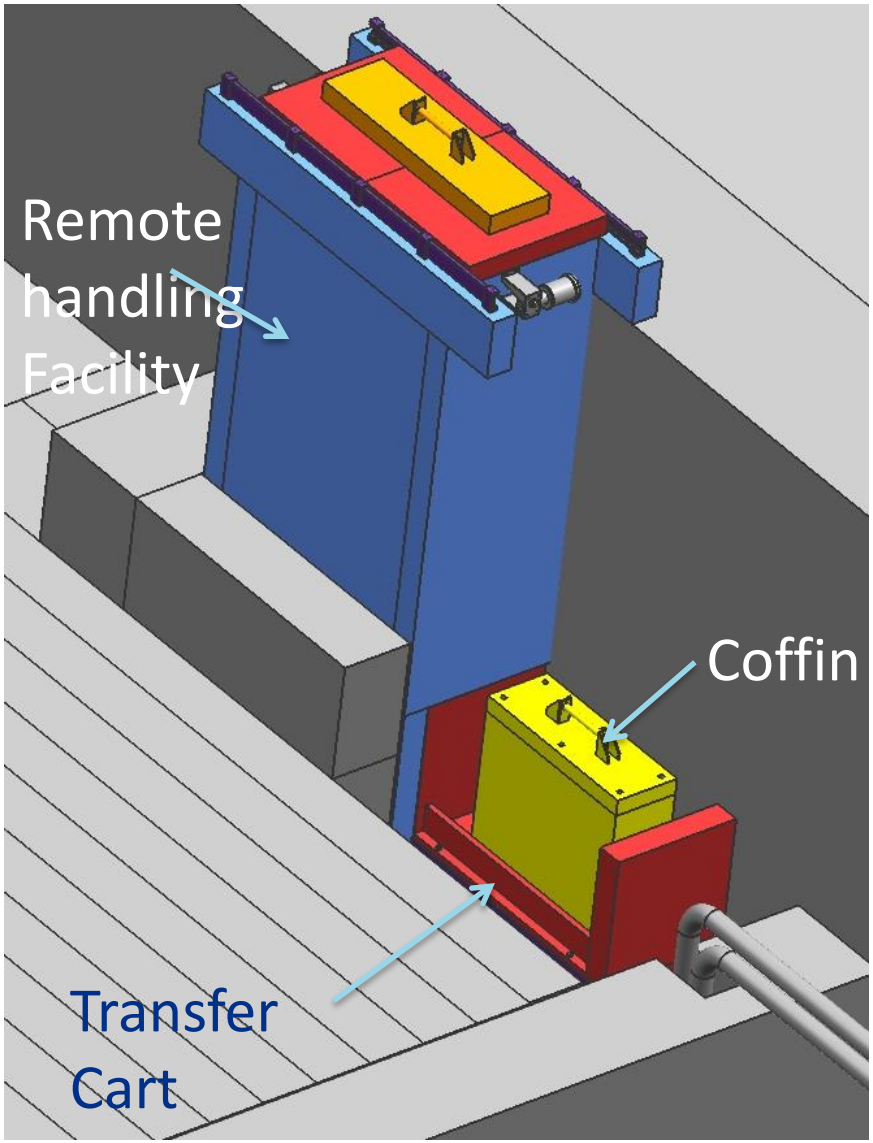


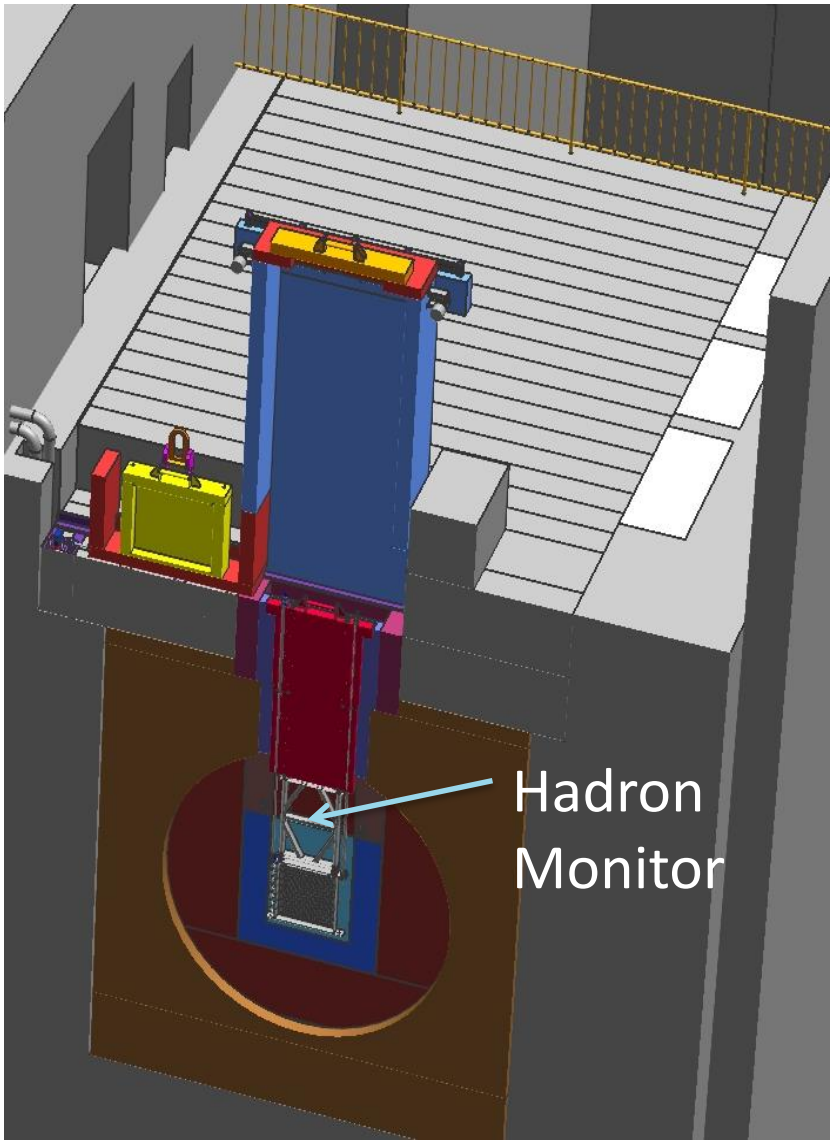


Hadron Monitor inside shielding block



Hadron Monitor Remote Handling

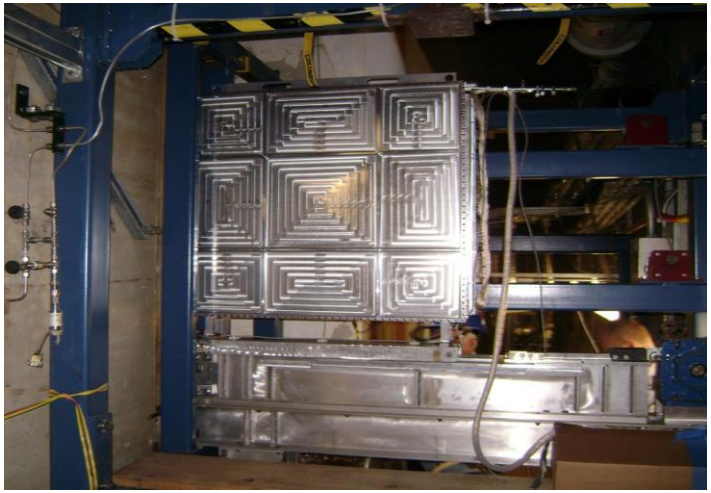


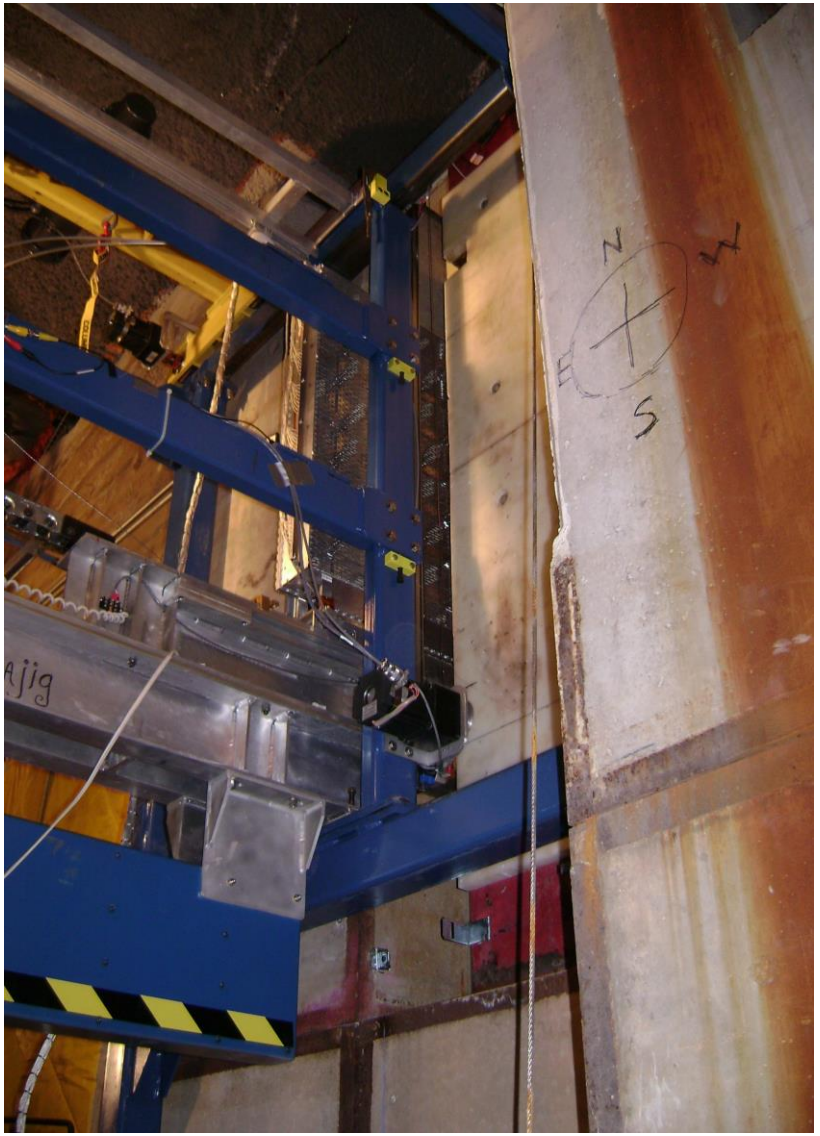


NUMI HM replacing fixture

NUMI Hadron Monitor

NUMI Hadron Monitor Installation





Conclusions

- The design of the absorber for the most conservative case, 2.4 MW beam and 1.5-m RAL Target, is well understood.
- The Absorber has been looked at as a system, that is, its core in combination with the surrounding steel shielding, the SS pan, the two cooling systems, and the remote handling systems were all assessed together.
- Operational experience, good engineering practices, and FESHM standards have been used to pick appropriate materials and designs.
- Prototyping of the critical components has also been done to understand fabrication challenges.
- 3 out of the 4 weld samples made after following all the procedures passed the weld qualification.